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Use of the AnnAGNPS Pollutant Loading Model for Prediction of Sediment Yields in a Mountainous Cumberland Plateau Region: Correlations with the Stream Bed Sediment Characteristics

Michael Patrick Massey
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Michael Patrick Massey entitled "Use of the AnnAGNPS Pollutant Loading Model for Prediction of Sediment Yields in a Mountainous Cumberland Plateau Region: Correlations with the Stream Bed Sediment Characteristics." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Environmental Engineering.

John S. Schwartz, Major Professor

We have read this thesis and recommend its acceptance:

Eric C. Drumm, Raymond Albright

Accepted for the Council:
Dixie L. Thompson

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Michael Patrick Massey
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Abstract

This study attempts to develop a relationship with the hillslope sediment yield (estimated from a computer model) and the deposited sediment particle size characteristics within stream channels. By using specific hydrological parameters within a watershed, a calibrated Annualized Agricultural Non-Point Source (AnnAGNPS) pollutant loading model was created for four different sub-watersheds in the mountainous New River Basin of eastern Tennessee. The AnnAGNPS pollutant loading model predicted daily runoff and sediment yield reasonably well, but it poorly predicted daily peak flow rate for most sub-watersheds analyzed in the New River Basin. Overall, the AnnAGNPS pollutant loading model provided satisfactory results in a mountainous, non-agricultural landscape with a limited amount of climatic data available. The average annual hillslope sediment yield, in terms of clays, silts, and sands, was calculated with the AnnAGNPS model for years 2006 and 2007, to compare with sediment deposition characteristics in the streams.

The fine particle size characteristics collected at specific bed deposition points were suspected to have a strong correlation with predicted sediment yield output from a calibrated AnnAGNPS pollutant loading model. The sites of the captured sediment were at locations just downstream of specific land use disturbances such as dirt roads, surface mining, and forest logging, all of which can be detrimental to the health of a stream environment and habitat if disturbances are not properly managed. In this study, the sediment collected at the channel bed deposition points represented the distribution of different material sizes that have recently moved within the stream during large discharge

events.

This investigation concluded that the certain measurements of the clays, silts, sands, and gravel material found in downstream sediment depositional points had a variety of significant relationships (p-value < 0.05) with the clays, silts, sands, and total sediment yield occurring on the watershed hillslopes. Overall, there are a limited amount of studies that analyze these collections of fine sediment deposited in areas of the stream that have interrupted velocity forces due to channel shape, objects, or formations. This study showed that the use of the AnnAGNPS pollutant loading model and the analyzation of specific fine sediment at depositional points in the stream, proper watershed management of a rural mountainous region can be better established.

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I would like to thank Dr. John S. Schwartz for serving as my major professor, a professional colleague, and a good friend. Dr. Schwartz has an incredible work ethic and asks the same from his students. He has continually provided me with difficult challenges as well as opportunities to grow throughout my graduate studies, but also helped me learn that practice of engineering must contain aspects of simplicity, humanity, and integrity to become well balanced.

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This study would have not been possible without the help of many others that have spent many hours assisting me collect measurements. Keil Neff, Tara Mallison, and Joe Parker are a select group that did not get funded through this contract, but provided many hours of their expertise within the New River Basin. I would like to thank Keil, Tara, and Joe for their friendship, advice, and responsible character they have offered.

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Finally, I want to thank the U.S. Department of Interior – Office of Surface Mining (OSM) for the Applied Science Program Grant Contract No. CT612054 and S07AP12477 which help fund my education and this study. Josh Baines, Daniel Johnson, Patrick White, and William Cantrell all were funded through the contract with OSM and helped collect field work and analyze the soil samples. Associated with the Knoxville District of OSM, I would want to recognize Rick Mann for all his advice and assistance within the New River Basin.

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Chapter 1: Introduction

Excessive sediment delivered to rivers and streams attributable to human activities can severely impact the local water quality, aquatic biota, stable stream geomorphology, and hydraulic characteristics (Salo & Cundy, 1987; Meehan, 1991; Simons & Senturk, 1992; Waters, 1995). Land use disturbances, such as forest logging, agriculture, urban development, and surface mining, can alter the mechanics of natural runoff, erosion, and sediment yield within a watershed (Haan et al., 1994). Once the natural terrain of a watershed has been altered by humans, the hydrological balance of the area is shifted and the change is passed down to the hydraulic characteristics of its receiving water bodies. For example, Nelson and Booth (2002) found that altered landscapes such as construction activities, agriculture, and gravel roads were large sources of fine sediment yield, while urbanization did not directly provide a large sediment yield into the streams. However, its high impervious nature increased runoff volume into the streams, causing channel bank erosion, which, in turn, produces large amounts of sediment (Bledsoe & Watson, 2001). Therefore, tools that can provide predictive capabilities to distinguish excess sediment production can be a powerful tool for natural resource management (USEPA, 1999).

Though erosion and sedimentation are natural processes when the land is not altered by humans, poor prevention management practices can cause major physical, chemical, biological, and economic impacts to all bodies of water (TDEC, 2002). To improve the water quality of degraded streams, the U.S. Environmental Protection Agency (USEPA) generates pollutant specific Total Maximum Daily Loads (TMDLs) for impaired watersheds (USEPA, 2008). In order to analyze multiple pollution sources within a watershed, many computer models have been developed to assist large stakeholders and managers make sound decisions to protect and improve the water resources in the nation (Merritt et al., 2003; Borah et al., 2006). The Annualized Agricultural Non-Point Source (AnnAGNPS) pollutant loading model is an invaluable tool for engineering and management practices involving erosion, sediment transport, runoff, and movement of pollutant loadings continuously in a watershed (Borah et al., 2006). Several studies have been produced from successful erosion and sediment yield predictions through the use of the AnnAGNPS pollutant loading model (Simon et al. 2002; Ming-Shu & Xiao-Yong, 2004; Zhen et al., 2004; Thames, 2005; Shrestha et al., 2006; Polyakov et al., 2006; Sarangi et al., 2007; Licciardello et al., 2007). Although many successful reports have been generated using the AnnAGNPS model, there are currently a limited amount of studies where this program has been used for pollutant predictive assessments on non-agricultural landscapes within a mountainous terrain. Therefore, it is unknown how well the AnnAGNPS pollutant loading model can predict sediment loads in a rural mountainous region that contains surface mining, forest harvesting, and dirt roads.

From rainfall in excess of abstractions, the highly variable process of sediment erosion, transport, and deposition are initiated on the hillslopes (Kirby et al., 2002; Newham et al., 2003; Fryirs & Brierley, 2003). When the amount of sediment load entering a stream reach is altered, the receiving channel's dynamic equilibrium is disrupted; this results in the geomorphological adjustment process of the channel's form and function (Vanoni, 2006). To obtain an estimate of the highly variable erosion and sediment yield process occurring from multiple sources in a watershed, a grain size distribution from various channel deposition points can be obtained. The characterization of the sediment found in channel depositional points allows for an estimation of the proportion of the fine sediment, from all sources in the watershed that is transported as washload in the streams (Reid & Dunn, 1996). The proportion of sediment found in these depositional points is thought to be a general snapshot of the size and amount of soil particles moving down the hillslopes and streams of a watershed over a period of several months to years (White, 2005). Also, it is worth noting that many reports have shown that an increase of fine sediment transported within streams can impair the benthic macroinvertebrates' habitat and well being (Waters, 1995; Angradi, 1999; Lowe & Bolger, 2000; Williams, 2005). Therefore, a link between the amount of sediment delivered to the channels, the fate of the transported sediment in channel depositional points, and the ecological consequences of an abundance of fine sediment in the streams has been established. The particle size distributions of the fine sediments in these channel bed deposition points, which classifies the soil in a percentage basis of clays, silts, sands, and other substrate, has the potential to assess the severity of suspended sediments transported within a stream system and its effect on the local aquatic organisms. Thus, the deposited fine sediment can help managers evaluate land use activities, major sediment sources, climatic change on the landscape, and the placement of erosion control techniques (Reid & Dunne, 1996).

The objectives of this study were to evaluate the accuracy of the AnnAGNPS pollutant loading model in a mountainous, forested watershed and to examine whether the average annual hillslope sediment yield estimated by the AnnAGNPS pollutant loading model correlated with measured fine particle size characteristics collected at specific bed deposition points in the New River Basin, Tennessee. Overall, this study should help natural resource managers identify the benefits and constraints of using the AnnAGNPS pollutant loading model in a mountainous watershed for non-agricultural land use disturbances, as well as using the particle size analysis on stream sediment deposits as a means of evaluating long-term historical sediment yield increases due to alterations within a watershed.

Chapter 2: Literature Review

2.1 Impacts of Rural Land Use Disturbances

Direct human disturbances to landscape, such as forest logging, agriculture, urban development and surface mining, can alter the mechanics of natural runoff, erosion, and sediment yield within a watershed (Haan et al., 1994). Currently, several government agencies, such as the Office of Surface Mining (OSM), the U.S. Forest Service (USFS), and U.S. Bureau of Land Management (USBLM), have been attempting to analyze and minimize various destructive land use activities for the future conservation of a watershed's streams, habitats, and communities for many years (Sennatt et al., 2006). Researchers and land managers are interested in the prediction of erosion and sedimentation rates as the watershed's land use patterns change as well as where sediment will be stored and for how long (Reid & Dunne, 1996).

The hydrology of a watershed is commonly explained through six major components: precipitation, infiltration, evaporation, transpiration, surface runoff, and groundwater flow (Viessman & Lewis, 2003). By changing the natural landscape of a watershed, five of the six major components of the hydrologic cycle can be heavily distorted, which can alter the erosion and sedimentation rates within a watershed (Reid & Dunne, 1996). Many human disturbances like urbanization, forest logging, surface mining, and agriculture result in less infiltration, transpiration, and groundwater flow, which leads to an increase in the local surface runoff to the streams (McBurnie et al., 1990; Waters, 1995; Wemple et al., 1996; Jones et al., 2000; Caissie et al, 2002; Wohl, 2006; Negley & Eshleman, 2006). Many watershed management studies are concerned with the effects of urbanization, while a lesser amount of research analyzes the rural land disturbances like forest logging, surface mining, and dirt roads (Thames, 2005). A large amount of these rural destructive activities can be seen in many mountainous communities of the U.S. and are usually caused from a lack of employment alternatives in nearby urban centers.

Cassie et al. (2002) observed that severely logged areas (more than 20% of the area of a watershed left deforested) had an increase in peak flow rates due to a loss of evapotranspiration and infiltration, due to the removal of trees and soils' decreased permeability from the movement of large logging equipment. Wemple (2001) showed that roads built for timber harvesting, as well as other transportation purposes in a forested watershed, can increase surfaces' impermeability, while promoting an increase in sediment transported to streams. Shown in Figure 1 is an example of a severely logged

Figure 1: Typical effects of forest logging seen in the New River Basin. (Smokey Creek Sub-watershed, 2007)

area within the New River Basin of Tennessee. It has also been presented that the skid trails found on the hillslopes of a logged area are the primary source of sediment yield within a rural forested watershed (Croke et al., 1999).

Surface mining for coal, like that of forestry, is currently very essential to the public's needs, but it can create pollution problems that affect the local streams, habitats, and quality of life. Since the mid-1800's, coal has been continually removed in the Appalachian Basin coal region, shown in Figure 2 (Ruppert, 1999). In comparison to a natural un-impacted forest environment, the nature of surface mining within the Appalachian Mountains has shown to increase the streamflow to local streams by the continuous movement of large machinery compacting the underlying soil's density (Negley & Eshleman, 2006). Within the Appalachian region, Stewart and Skousen (2003) found that the water quality of heavily mined parts of the watershed was much poorer than that of abandoned or minimally surface mined sites.

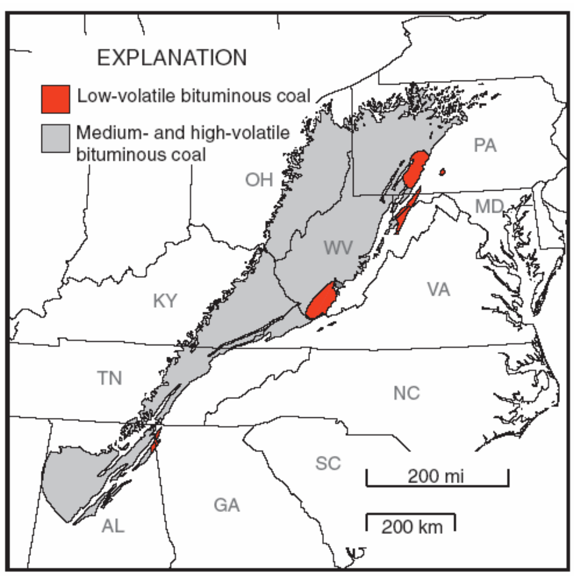


Figure 2: Regional Appalachian Coal Basin (Ruppert, 1999).

Igo (2005) documented several streams that were in a current state of instability and severe erosion due to upland sources of historical surface mined sites in the mountainous terrain of West Virginia.

As with all rural mountainous areas that have an abundance of logging and mining, there are loose gravel and dirt roads, which are sewn into the landscape. Jones et al. (2000) found that road systems in a mountainous forest environment can increase the transport of sediment while also increasing a watershed's surface runoff directly to the streams. By altering the hydrologic and geomorphic characteristics of a watershed, rural road networks placed in typical mountain forested environments have been shown to impact the function of local stream networks (Wemple et al., 1996). For areas that see a large amount of logging or coal mining in a rural watershed, the amount of traffic on the road system is bound to increase. Sheridan et al. (2006) found that increased traffic on loose gravel roads in a forested environment can increase the amount of sediment to a stream. From recent study by Ramos-Scharron and MacDonald (2007), a large amount of storm water runoff and sediment yield are produced by dirt roads and measured, as well as predicted amounts of sediment yield from dirt roads has much variability. Sugden and Woods (2007) showed that sediment from unpaved is based on many variables, such as material characteristics, frequency of use, slope, and age but is a difficult parameter to estimate.

2.2 Hillslope Sediment Yield into Streams

Sedimentation within a stream system can only occur from within the channel through bank erosion or from sediment yield upon the watershed's hillslopes (Delleur, 2001). When a large precipitation event passes over an area, the runoff caused from the storm water will transport clays, silts, and sands (particles diameter less than 2.0 mm) from the hillslopes from various land use disturbances, which eventually form sediment deposits in the stream (Sennatt et al., 2006). Therefore, these fine sediments will be transported from a watershed's hillslopes into the local streams during a storm event, owing to storm water runoff. Figure 3 provides a general flowchart of the typical relationships among sediment mobilization, production, deposition, and yield found in a watershed (Reid & Dunne, 1996).

After the watershed's sediment yield enters into a stream network, the entering sediment travels in the stream by reason of the transport capacity of the stream's flow

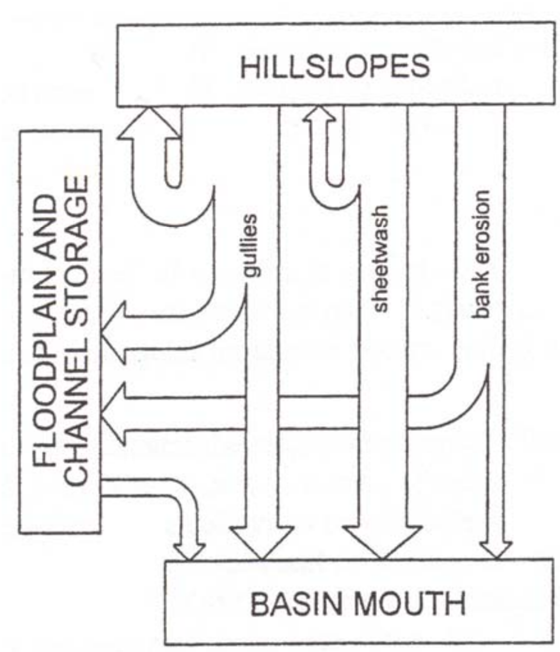


Figure 3: Typical sediment budget flowchart (Reid & Dunn, 1996).

(Hann et al, 1994). When the flow and velocity of a stream decrease, the fine sediment particles settle as a result of the resisting forces of the particles being greater than the applied forces of the stream (Chang, 1988). When the resistant forces of a particle are greater than the applied force from a stream's flow, the submerged weight of the particle will dominate which leads to sediment deposition. Thus, a stream's change in hydraulics or an increase in sediment supply can decrease the transport of the sediment particles and cause deposition in the channel (White, 2005).

Reid and Dunne (1996) suggest that "each erosion process produces a characteristic size distribution of sediment" (p. 50). The collections of bed sediment, which indicate a history of fine particles that are transported by the stream during high flow, are found in a variety of specific depositional locations in each stream reach (White, 2005; Williams, 2005). Channel deposition points are hydraulic locations in the stream that have inconsistent velocities in comparison to the overall stream movement during average flow conditions. The fine sediment transported in the stream is deposited in point bars, side bars, or behind objects like large boulders in the stream that shield the natural flow during variations of stream discharge intensity

Several commonly used methods that measure the amount of sediment deposited in stream channels, have revealed to have statistically different similarities of the same parameter (Sennatt et al., 2006). Overall, Sennatt et al. (2006) also illustrated that the same sediment protocol applied throughout a channel reach will produce irregularities in the percentage of fines measured, but should be somewhat consistent in unregulated streams. White (2005) suggested that some river systems see a cycle of supply-transport-deposition, which is continually repeated so that transported sediment within a channel will eventually deposit in a stream for long periods of time. In other words, the sediment deposits found in the stream from deposition can show some historical significance for erosion and sediment yield upstream of that point of interest.

A special case of sheetwash erosion of the hillslopes is that of road surfaces found within a watershed. From several field investigations within the New River Basin of Tennessee, many of the heavily disturbed sub-watersheds have a majority of dirt and gravel road routes that are found near the streams and continuously re-supplied with fine gravel particles after large rainfall events. With the steep slopes, traffic density, and minimal stream buffering area to absorb the sediment, a direct source of sedimentation to many of the sub-watersheds in the New River are assumed to be due to the dirt and gravel roads. Reid and Dunne (1996) suggest that for many forest environments, the dirt roads are often the major source of sediment yield entering a watershed's streams. As with most sediment studies, the predicted sediment yields from dirt roads contains a large amount of variability (Ramos-Scharron & MacDonald, 2007). The prediction of sediment yield from dirt roads is complicated by the ever changing soil parameters, flow lengths, road-side ditches, and geometries all found in close proximity, as well as the traffic intensity, the constant re-supply of sediment, and drainage systems. Since the dirt roads are an important variable to express the amount of sediment entering the streams of the New River Basin, this study will further develop a protocol to account for this special type of sheetwash erosion from the landscape. Figure 4 provides an example of the sediment that is transported to the streams from dirt roads within the New River Basin.

Figure 4: Dirt road sediment yield discharging to Montgomery Fork. (2007)

2.3 AnnAGNPS Pollutant Loading Model

With the current technological advances, several computer programs have been developed in the recent years to better manage sediment yield within a watershed (Merritt et al. 2003; Borah & Bera, 2003). The Agricultural Non-Point Source (AGNPS) pollutant loading model was created to evaluate and manage the severity of surface erosion, nutrient and pesticide transport, and related stream channel reactions caused by the degree of different storm events to the local geography, soil types, hydrology, and land use applications found within the watershed.

The AGNPS pollutant loading model was created through the U.S. Department of Agriculture (USDA), Agriculture Research Service (USDA-ARS) with the assistance of the Minnesota Pollution Control Agency (MPCA) and the Soil Conservation Service (USDA-SCS) in order to collectively attain data and personnel needed to develop and facilitate the program and to successfully create a management tool for watersheds with a greater part of agriculture activities (Young et al., 1989).

The most recent version of AGNPS has the capabilities to simulate the movement of non-point source pollution (water, sediment, nutrients, and pesticides) and chemical point source pollutants throughout the watershed through different hydraulic scenarios. By using a Geographical Information Systems (GIS) interface for the program, the watershed is broken into cells based on the Digital Elevation Models (DEMs), land use, and soil type. Each cell contains a constant slope, length, elevation, land use cover, management practice, and soil type value. These cells are linked together to form streams (reaches) and are then used to simulate the movement of runoff after precipitation events, which carry the non-point source pollutant the user is studying. The cells and their corresponding reaches can simulate the movement of water, sediment (by particle size and source), and various chemicals. Currently, the types of chemical complexes that AGNPS can simulate are nitrogen, phosphorus, organic carbon, and pesticides for agricultural activities.

The Annualized Agricultural Non-Point Source (AnnAGNPS) pollutant loading model is an extension of the AGNPS program and is an valuable tool for engineering and management practices involving erosion, sediment transport, runoff, and movement of pollutant loadings continuously in a watershed (Borah et al., 2006). Several articles have been produced from successful erosion and sediment yield predictions through the use of the AnnAGNPS pollutant loading model (Simon et al. 2002; Ming-Shu & Xiao-Yong, 2004; Zhen et al., 2004; Thames, 2005; Shrestha et al., 2006; Sarangi et al., 2007). AnnAGNPS has been developed by the United States Department of Agriculture – Agriculture Research Service (USDA-ARS) and the Natural Resources Conservation Service (USDA-NRCS) (Simon et al., 2002). Like the AGNPS model, the AnnAGNPS is written in the ANSI Standard FORTRAN 90 language and was originally developed for management scenarios in agricultural settings to control sediment, nutrient, and pesticide transport to nearby streams. In contrast to the AGNPS program, the AnnAGNPS system is used for long-term analysis of pollutant transport, where AGNPS is made for a single event simulation (USDA, 2000).

The AnnAGNPS pollutant loading model uses a GIS interface (ESRI ArcView 3.X) that must have Digital Elevation Models (DEM), USDA-NRCS soil layers, and land use (field management) data layers to characterize the watershed of interest. After all the required GIS layers have been collected, they must be imported into the modified ArcView GIS program called the AnnAGNPS-ArcView Interface. The AnnAGNPS-ArcView Interface combines several GIS programs into one so that the manipulation of different watershed characteristics can be computed in one single program. The AnnAGNPS-ArcView Interface contains two combined programs to represent the Flow Net Generator: USDA-ARS TOPAZ Version 3.1 (an automated digital landscape analysis tool which contains three programs under it DEDNM, RASPRO, RASFOR) and AGFLOW to help create grids of the watershed that contain cells with homogeneous characteristics (USDA, 2000). The AnnAGNPS program also contains a Windows-based

Input Editor to help define all the parameters within the watershed's hydrological calculations. One of the critical sources of information required to properly define reasonable flow cells is a high resolution DEM that covers the entire watershed to be simulated. The DEM layer in the AnnAGNPS-ArcView Interface is used to generate individual cells through the Flow Net Generator that have a uniform slope, length, elevation, and shape. The Flow Net Generator also uses the DEM layer to define all the streams that eventually flow to the outlet of the watershed. Several other GIS layers are required in the AnnAGNPS program to define the land use activities and soil types.

The AnnAGNPS program creates a grid within the watershed that has individual cells that contain a homogenous soil type, land use cover, management practice, and topographical (slope, length, and elevation) characteristics to calculate erosion within the watershed. For ease of the program's computations, the most dominant soil type and land use is assigned to each cell polygon that surrounds that area and is used for the process of determining the amount of erosion, sediment yield, runoff, and pollutants transported for a daily storm event in the watershed. In other words, several cells connected together in a watershed will only accept a single land use, soil type, slope, length, elevation, and management practice that is representative of the area in the watershed it is located. Current soil information used in the AnnAGNPS program can be obtained through the USDA-NRCS or be created by the user. The USDA-NRCS contains many files and GIS information around the U.S. which makes the AnnAGNPS program easier to develop for a specific project. The land use cover GIS information in the U.S. is found from the USGS Seamless Data Distribution System, but the input parameters used to define the land use cover may have to be specifically estimated by the user and other specific organizations with the USDA.

The AnnAGNPS pollutant loading model determines the size of each cell by its Critical Source Area (CSA) and Minimum Source Channel Length (MSCL) (Shrestha et al., 2006). With the CSA and the MSCL, the user has the option of defining the size of cell groupings in order to better define a watershed that may have a large variety of different soils, land use, and topography information. The MSCL represents the minimum reach length in meters that connects a set of cells with the same runoff route (usually a stream or tributary within the watershed). The CSA is the minimum area of cells that are created around a reach in hectares. It is recommended that the MSCL value is no smaller than the DEM resolution and that the CSA is no less than the DEM resolution squared.

To estimate the erosion, sediment yield, and runoff, the AnnAGNPS program uses the Revised Universal Soil Loss Equation (RUSLE) Version 1.05, the Hydro-geomorphic Universal Soil Loss Equation (HUSLE), and the USDA-NRCS Technical Release 55 (NRCS TR-55) methods used for calculating peak flow, Soil Conservation Service (SCS) Runoff Curve Numbers (CN), and the Time of Concentration (Tc) (Shrestha et al., 2006). The AnnAGNPS program uses RUSLE to take land cover, soil, management practices, topography, and precipitation values for each cell and then calculates the daily sheet and rill erosion. RUSLE, like the AnnAGNPS model, is used to represent the process of hillside erosion over a long period of time. After the process of rill and inter-rill erosion have been estimated for each cell, HUSLE is used to calculate the sediment yield from each cell to a stream reach after deposition from runoff. Because RUSLE does not assume any deposition from sheet and rill erosion, AnnAGNPS model uses HUSLE to create a delivery ratio to determine the amount of deposition occurring from the erosion and sediment yield for five separate soil particle sizes (clay, silt, sand, small and large aggregates) based on each particle's mass fall velocity (Bingner et al., 2003). Therefore, the sediment yield is defined by percentages of the five soil particle sizes for each cell or reach in the defined watershed.

When a storm event is simulated in the AnnAGNPS software, several sets of hydrological calculations are used to create a realistic and accurate hydrological environment. Before runoff, erosion, and sediment yield occur, the AnnAGNPS program accounts for the evapotranspiration from the simulated rainfall as a function of potential evapotranspiration (Penman Equation), and the soil's moisture and the percolation of the soil are computed with the Brooks-Corey equation (USDA, 2000). After evapotranspiration and the soil's moisture have been accounted for, three items, CN, Tc, and the Storm Distribution Type, are collected from the *NRCS TR-55 Urban Hydrology for Small Watersheds* manual in order to calculate how the watershed reacts to daily hydrological events (Bingner et al., 2003).

As the AnnAGNPS program simulates daily precipitation events, the 24-hour rainfall is matched to a storm distribution curve from NRCS TR-55 that defines the energy of the occurrence uniformly for all cells created in the watershed. Daily runoff amounts, caused from the daily storm events, from each cell in the watershed are estimated using the CN technique coupled with soil, land cover, and land management information for each cell by the AnnAGNPS model. The AnnAGNPS pollutant loading model takes the CN that is entered by the user and uses the related soil retention value and soil moisture adjustment for each CN and creates algorithms to calculate the runoff generated for the cells within the watershed (Shrestha et al., 2006). Next, the peak flow of runoff within each cell reach is broken up into three categories (overland, concentrated, and channel flow) to better estimate the Tc within the AnnAGNPS model through the NRCS TR-55 graphical peak discharge method, which is slightly modified (sometimes called the Extended NRCS TR-55 method) by Theurer & Crohshey (1998).

The most important variable for an accurate representation of a hydrological model is the climate. The climate information can be imported into the AnnAGNPS Input Editor if the user has enough detailed information on the historical weather for a project. The required climate variables needed in the AnnAGNPS model are all daily values including maximum temperature, minimum temperature, precipitation, average dew point, sky cover, wind speed, and solar radiation. For annual average sediment yield estimates, a continuous set of daily climate values for at least a one year period must be obtained. Since such are large set of climate data is required to accurately run the model, an area of study may not have enough climate data or any historical weather information in close proximity. The Generation of weather Elements for Multiple applications (GEM) computer model is also installed with the AnnAGNPS pollutant loading model for approximate climate generation when non-existent weather data is available to a specific location. GEM is developed to help define all the climate data for a location. The GEM program was developed by scientists from the USDA-NRCS, USDA-ARS, and various universities. Currently, the GEM system is programmed and maintained by a specific staff of USDA scientists at the National Water and Climate Center in Portland, Oregon. The GEM is a stochastic weather simulator that produces all required climate data needed in the AnnAGNPS modeling software and is generated through statistically represented time series of daily weather values based on the location of the site. Johnson (1996, 2000) declares that GEM has shown to simulate accurate weather conditions for various locations when compared to the true climate data collected at a specific site.

The AnnAGNPS Input Editor contains tabular data that defines the GIS shapefiles to establish several variables found in the calculations for erosion, sediment yield, runoff, and transport of various chemicals and point sources. When the AnnAGNPS program has been set up correctly, the majority of the GIS data layers can be viewed within the system's Input Editor. The Input Editor contains a spreadsheet of all the data collected from various the GIS layers used, individual cell characteristics, reach information important to the cell flow paths, daily climate information, and management practice (USDA, 2000). Depending on the extent of simulation, various parameters must be imported into the Input Editor. For a basic simulation of runoff, erosion, and sediment yield within a watershed, the Input Editor will automatically sort all the information within each cell and reach, but data pertaining to the soil, climate, field management, and CN for each land use must be entered into the Input Editor before the AnnAGNPS program can fully complete the simulation. For the simulation of runoff, erosion, and sediment yield within a watershed, eleven different sections of the AnnAGNPS Input Editor have had to be completed for this study: AnnAGNPS Identifier Data, Cell Data, Climate (Daily Climate Data), Management (Field Data & Schedule Data), Non-Crop, Reach, Runoff Curve Number (CN), Simulation Period, Soil, Watershed, and the Output Options data fields. Of these eleven sections of the Input Editor, the CN, Non-Crop, and Management Field Data contain several user-defined variables to hydrologically define the land use and land cover applications found with in a watershed. These parameters, which are used in the USDA-NRCS TR-55 computations for runoff and the RUSLE and HUSLE calculations for erosion and sediment, yield respectively for each defined cell in the AnnAGNPS pollutant loading model.

After all critical information for each individual cell within the watershed has been processed through the AnnAGNPS model and the corresponding Input Editor, the runoff, erosion, sediment yield, and other chemical pollutants attributable to each cell and reach are calculated with daily precipitation values over a continuously long term time period. The overall simulation within the watershed is for all the cells, linked together, to establish a cumulative runoff value containing the hillslope sediment yield and any nutrients in the stream as a result of a storm event on the landscape, which travels to the outlet of the watershed. The soil loss throughout the watershed can be analyzed based on the suspended sediment's particle size distribution. The ability to estimate amounts of silt, sand, clay, and aggregate movement at various portions of a watershed is a feature that may not be available with various current watershed models that simulate sediment transport, but AnnAGNPS can specifically detail the amounts of sediment movement for all the reaches' flow to stream outlets (Merritt, Letchen, & Jakeman, 2003).

Aside from the standard sediment yield that is calculated in AnnAGNPS for each cell, other features are included within the program to simulate concentrated sources of impact. The extra features found in AnnAGNPS (feedlot simulation for nutrients, gullies for sediment, point sources for nutrients, impoundments for sediment, and irrigation practices) can all be applied to the cells in the watershed of interest in order to obtain a more accurate representation of the area's hydrology (USDA, 2000).

The study of sediment supply, transport, and deposition are complex processes and require a complex set of data and calculations. Computer models can provide an efficient alternative, when compared to hand computations, when determining management techniques associated to sediment control (Sarangi et al., 2007). It must be noted that there are many errors involved with developing models to estimate erosion and sediment yield within a watershed. For example, White (2005) mentions that land use, climate, stream flow variability, and sediment concentration have the potential to induce error into a watershed model since soil erosion, sediment yield, and deposition have such a strong dependence on both space and time.

Though a multitude of AnnAGNPS particle transport studies related to agriculture or urbanization have been successfully published, there are no present articles that demonstrate the use of AnnAGNPS in a rural region that contains a large amount of disturbances in the form of surface mining, forest harvesting, and dirt roads. Recently, a case study in a northern mountainous California terrain successfully applied the AnnAGNPS pollutant loading model to mimic historical sediment yields from land use disturbances such as urbanization, agriculture, forestry, and recreational activities (Simon, 2004). Though the AnnAGNPS pollutant loading model was initially created for agricultural watershed management applications, it can be quite helpful for various sedimentation management applications and studies.

2.4 Stream Bed Sediment Measurements

Clays, silts, and sand particle sizes of predicted sediment yield at the outlet of a user-defined watershed from a calibrated AnnAGNPS pollutant loading model can indicate the amount of sedimentation entering the streams. Commonly, the amount of suspended solid-phase material in a stream is measured from the use of suspended sediment samplers during storm events, which provide a concentration of transported sediment in a moving body of water from various sources (Gray et al., 2000). Many reports have shown that an increase of fine sediment in streams can impair the benthic macroinvertebrates' habitat and well being (Waters, 1995; Angradi, 1999; Lowe & Bolger, 2000). In the Appalachian Mountain region, areas with reduced forest cover (from logging) were correlated with high amounts of sediment in the form of silts and sands, which led to a decrease of certain fish assemblages and habitats for spawning (Sutherland et al., 2002). Williams (2005) found a correlation between the fine particle sizes in sediment deposits in the stream bed to the biological integrity of benthic macroinvertebrates' indices within the Ridge and Valley Ecoregion of Tennessee. From her work, it is thought that these sediment deposition points in the channel bed contain a historical mixture of suspended sediments transported in the stream during storm events and settle in less turbulent portions of a stream. The particle size distributions of the fine sediments in these channel bed deposition points can lead to possible assessment of the severity of suspended sediments transported within a stream system. This efficient assessment of the deposited fine sediment can help managers evaluate the impacts of land use activities, climatic change on the landscape, and placement of erosion control techniques within a watershed (Reid & Dunne, 1996).

Chapter 3: Methods and Procedures

3.1 Description of Study Area

3.1.1 New River Basin

The study area, located in the Mountainous Cumberland Plateau region of Tennessee, is within the New River Basin (seen in Figures 5 & 6). The New River Basin has seen a long history of forest harvesting and coal mining since the late 1800's (Gardner, 2006). Due to the incorporation of state and federal environmental protection laws the New River Basin currently contains a reduced amount of logging and surface mining, compared to historical records, but these limited disturbances on steep sloped terrain are still problematic and can possibly be better analyzed and managed through the

Figure 5: Overlooking the New River Basin. (Windrock Mountain, 2006)

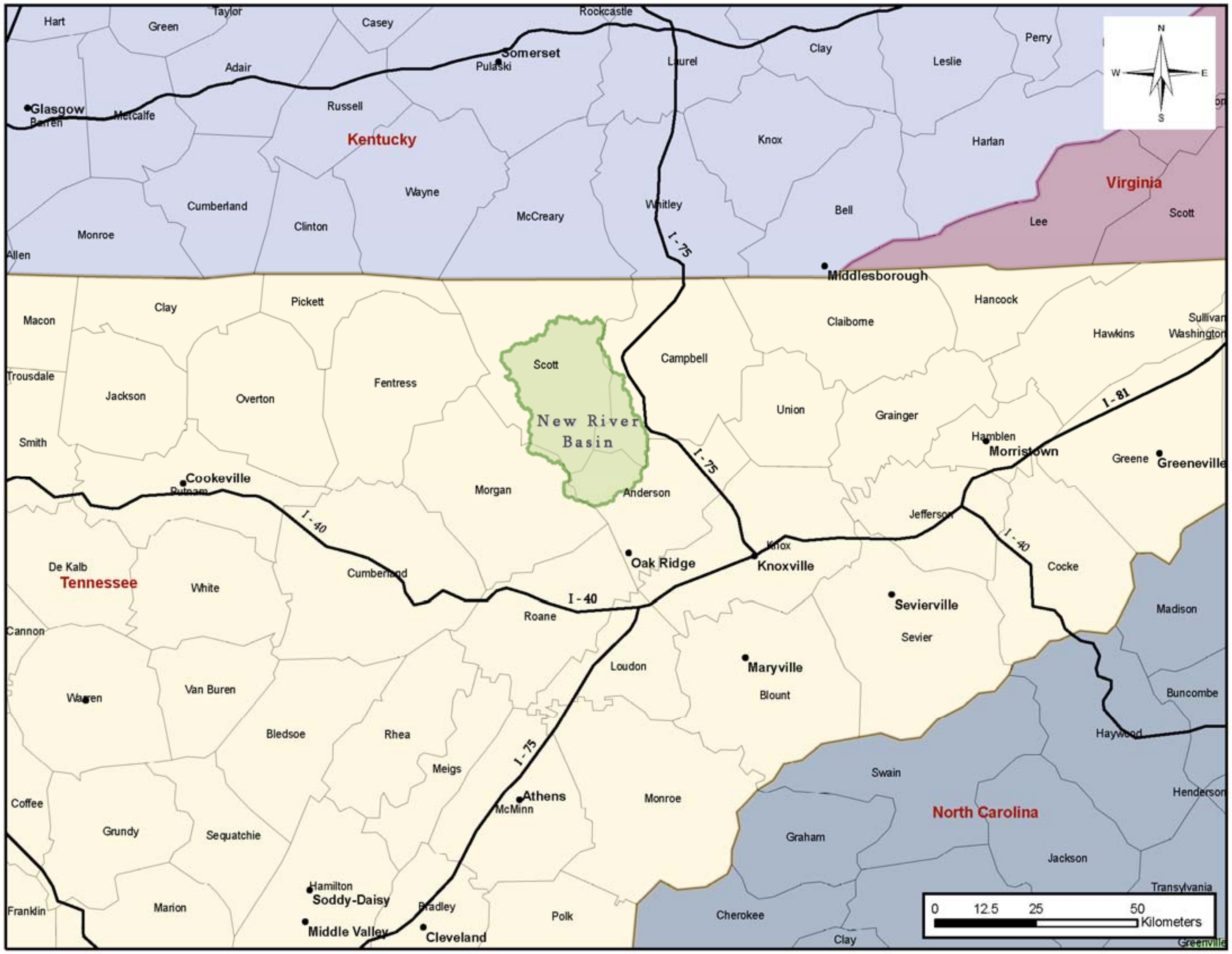


Figure 6: Location map of the New River Basin, Tennessee.

stream bed sediment deposition characteristics and the prediction of problematic sources of fine sediment entering into the New River.

The New River begins near the Frozen Head State Park of Tennessee (which is just north of Oliver Springs, Tennessee and east of Wartburg, Tennessee) and forms the outlet of the basin when it intersects with the Clear Fork stream. At the New River and Clear Fork confluence, the South Fork Cumberland River begins near the 497 km^2 (192 mi^2) Big South Fork National River and Recreation Area. The New River Basin, which is just southeast of the Big South Fork National River and Recreation Area contains a drainage area of 1026 km^2 (396 mi^2) and is completely contained in Anderson, Campbell, Morgan, and Scott counties of Tennessee (Carey, 1984).The New River Basin is a sub-basin of the South Fork Cumberland Basin (HUC 05130104), which is part of the Ohio Water Resource Region (HUC 05). It contains a rugged terrain ranging in elevation from 335 m to 1006 m (1100 ft to 3300 ft) with an average hillslope of 25% (Overton, 1980).

The New River Basin is located in the humid climatic regions and has a moderate average annual temperature of 12.3°C (54.2 °F) and an abundant 1358 mm (53.4 inches) of annual rainfall. The area's climate tends to be the warmest in the month of July, which has an average temperature of 23.3°C (73.9 °F), while the coldest time of the year occurs in the month of January with an average temperature of 1.0°C (33.8 °F) (NOAA, 2002). Therefore, this area observes warm to hot summers and mild winters.

After analyzing the precipitation trends throughout each month for the New River Basin, the most rainfall seems to occur in March with a value near 133.35 mm (5.25 inches) but continues throughout the summer months with monthly precipitation values near 127.0 mm (5.0 inches). The autumn season of September through October usually contains the least rainfall at an amount of 76.2 mm (3.0 inches). Usually this area will see about an annual average value of 1,270 mm (50 inches) of rainfall and 432 mm (17 inches) of snowfall in the mountains (Overton, 1980).

The New River Basin is part of the Appalachian Plateau physiographic region, locally called the Cumberland Plateau in the Kentucky, Tennessee, and Alabama areas. Appalachian Plateau is the western-most section of the Appalachian Mountains and is divided into four sub-categories: Cumberland Plateau, Cumberland Mountains, Allegheny Plateau, and the Allegheny Mountains (USGS, 2003).

The geologic formations of the Cumberland Plateau are from the Mississippian (360-320 million years ago) and the Pennsylvanian periods (320-296 million years ago). The sediments that were hardened during these geologic periods created an abundance of coal, shale, sandstone, and limestone within the area (NPS, 2007). With a large amount of these rock types in the region, there are a vast amount of caves, karsts, cliffs, waterfalls, and boulders.

A majority of the soils found in the New River Basin, as well as the Cumberland Plateau, are thin, infertile, and not very popular for most agricultural practices. The soils of the basin are diverse and range from deep loamy and clayey soils on the mountains to well drained, moderately deep clay subsoils and silty clay topsoils on ridge tops, to well drained silty clay loam soils at lower elevations (Overton, 1980).

3.1.2 Study Sub-watersheds

Four sub-watersheds found in the New River Basin were selected based on variations of rural land use disturbances observed. Of the four sub-watersheds, three of them have been defined as impacted (heavily disturbed): Montgomery Fork, Ligias Fork, and Smokey Creek. The fourth sub-watershed of interest in the New River Basin (Brimstone Creek sub-watershed) is used as an un-impacted (minimally disturbed or reference) sub-watershed for comparison with disturbed areas in the same region. Figure 7 shows the locations of all the four sub-watersheds of interest and the location of the various sediment collection points obtained within the major streams networks.

Montgomery Fork, Ligias Fork, and Smokey Creek all contain a large amount of forest logging, abandoned surface mined areas (reclaimed and un-reclaimed), and dirt roads. The only potential non-point sediment sources found within the reference sub-watershed, Brimstone Creek, is a small percent of dirt roads, logging, and abandoned mining areas at the outer points of the watershed. Table 1 provides an approximate amount of disturbances found in each of the four sub-watersheds used in this study for the year of 2006.

3.2 Study Design

The objectives of this study were to evaluate the accuracy of the AnnAGNPS pollutant loading model in a mountainous, forested watershed and to examine whether the average annual hillslope sediment yield estimated by the AnnAGNPS pollutant loading model correlated with measured fine particle size characteristics collected at specific bed deposition points in the New River Basin, Tennessee. A calibrated AnnAGNPS pollutant loading model provided average annual values of sediment yield

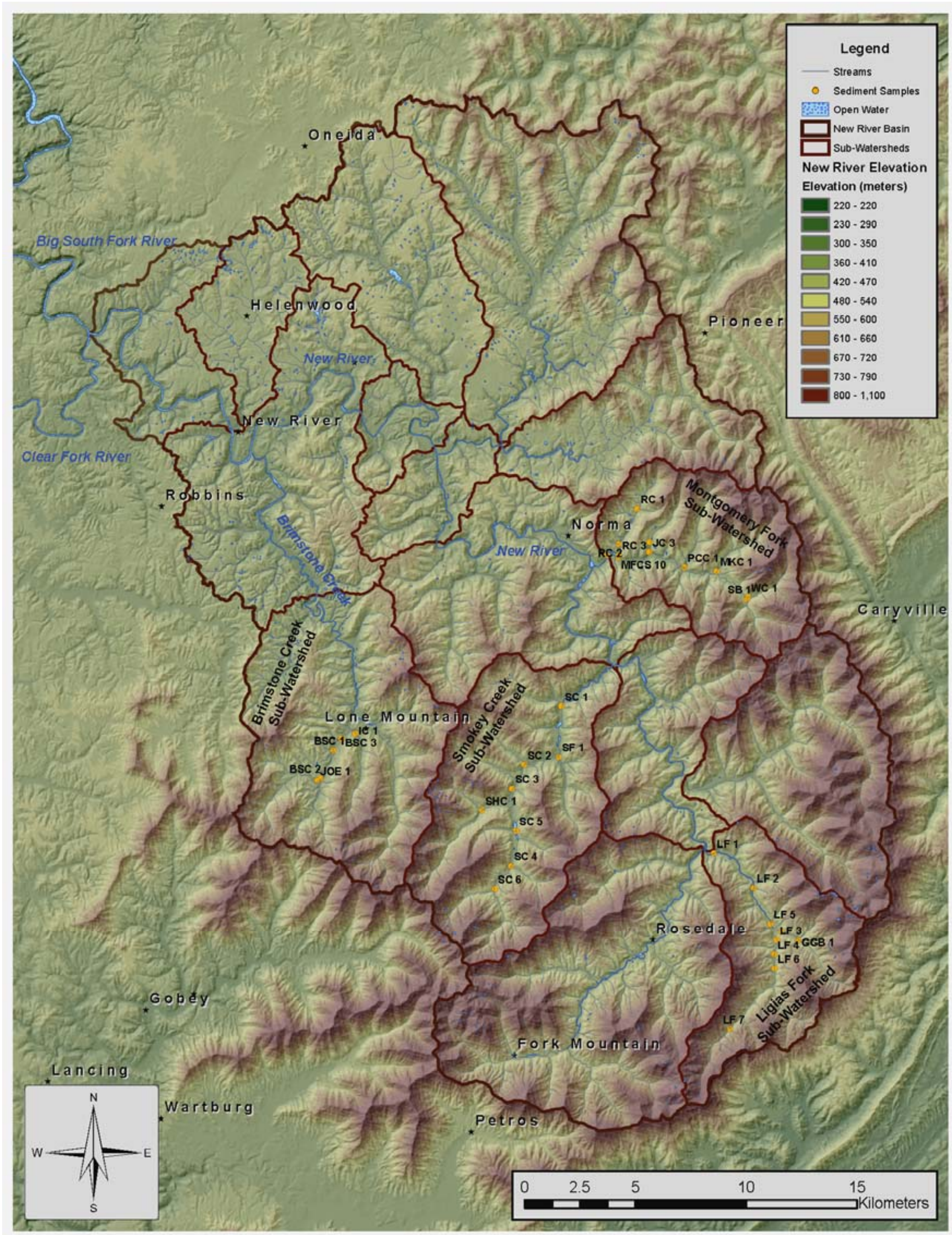


Figure 7: Location map of bed sediment samples collected in the New River Basin.

Table 1: Land use defined for each sub-watershed in the New River Basin. (2006)

Land Use Classification	Watershed Area Occupied							
	Smokey Creek (m^2)	Smokey Creek (%)	Ligias Fork (m^2)	Ligias Fork (%)	Montgomery Fork (m^2)	Montgomery Fork (%)	Brimstone Creek (m^2)	Brimstone Creek (%)
100% Logged	580,098	0.67%	0	0.00%	0	0.00%	0	0.00%
75% Logged	2,886,302	3.33%	4,213	0.01%	743,932	1.30%	0	0.00%
50% Logged	3,177,084	3.66%	707,456	1.33%	1,159,430	2.02%	603,400	1.80%
25% Logged	5,261,740	6.07%	2,176,537	4.10%	4,669,355	8.13%	521,068	1.55%
Abandoned Surface Mining	3,851,843	4.44%	3,624,669	6.83%	1,821,261	3.17%	607,920	1.81%
Active Surface Mining	506,845	0.58%	242,875	0.46%	362,261	0.63%	0	0.00%
Dirt Roads	833,694	0.96%	708,265	1.33%	495,703	0.86%	148,130	0.44%
Developed, Open Space	1,920,556	2.21%	755,674	1.42%	1,286,000	2.24%	533,214	1.59%
Developed, Low Intensity	44,510	0.05%	26,868	0.05%	872	0.00%	4,605	0.01%
Developed, Medium Intensity	0	0.00%	15,903	0.03%	6,630	0.01%	0	0.00%
Barren Land (Rock/Sand/Clay)	16,628	0.02%	17,565	0.03%	2,689	0.00%	0	0.00%
Deciduous Forest	63,678,228	73.40%	40,069,883	75.45%	45,178,748	78.66%	27,998,743	83.40%
Evergreen Forest	3,254	0.00%	13,959	0.03%	38,483	0.07%	105,319	0.31%
Mixed Forest	2,212,644	2.55%	3,298,107	6.21%	1,432,744	2.49%	2,538,730	7.56%
Shrub/Scrub	429,477	0.50%	14,328	0.03%	37,868	0.07%	47,580	0.14%
Grassland/Herbaceous	965,015	1.11%	1,361,588	2.56%	164,453	0.29%	188,390	0.56%
Pasture/Hay	296,366	0.34%	71,824	0.14%	9,568	0.02%	273,577	0.81%
Woody Wetlands	87,401	0.10%	0	0.00%	25,550	0.04%	2,279	0.01%
Total	86,751,582	100.00%	53,104,609	100.00%	57,435,358	100.00%	33,572,998	100.00%

Note: Data used is from a combination of sources (USGS, DOI-OSM, & TWRA) with modifications from 2006 Arial Photography (Raster Images) occurring from a multitude of different land use activities within a watershed. Because the four individual sub-watersheds found in the New River Basin have a variety of different land use disturbances, the calibrated AnnAGNPS pollutant loading model was used to estimate an average annual sediment yield at specific stream reaches in each sub-watershed where fine stream sediment was collected and defined by a particle size distribution.

The fine sediment was collected at a variety of specific stream deposition points located in each of the four sub-watersheds of interest. All of the sub-watersheds' stream routes, where stream sediment was obtained, eventually enter into the New River. The bed sediment located at specific deposition points were obtained in a spatially random order to test a variety of different stream networks that receive various amounts of hillslope sediment from different land use disturbances. The location of sampled stream bed sediment in each sub-watershed was chosen to best represent the each sub-watersheds' stream network. By taking sediment samples at a mixture of different streams and locations where hillslope sediment yield from land use disturbance would be transported, the greater the variations in sediment yield with the stream sediment deposits could be analyzed. Overall, 33 samples of stream bed sediment were acquired, which is due to the limitation of time with this study.

At each stream site, the Rapid Geomorphic Assessment (RGA) measurements were taken where the channel bed sediment samples were also collected. The RGA analysis was developed by Dr. Andrew Simon in collaboration with various scientists at the USDA National Sedimentation Laboratory in Oxford, Mississippi. Successful application of the RGA form has been applied to various streams within different ecoregions to grade the stability of a channel and therefore assess the delivery and flow of sediment in a channel (Simon, 2004b). The RGA analysis is a means of quickly determining the current stability and geomorphic characteristics of a stream's reach (Simon, 2004). RGA surveys score a stream reach numerically. If a stream reach has an RGA score less than 20.0, then the stream reach is stable and not a major source of sedimentation.

Next, the fine bed sediment collected in the streams was processed to better define its characteristics through the use of particle size distributions. Near the outlet of all four sub-watersheds in the New River, Global Water™ Stage Recorders (Model No. WL-16)were installed to document the change of stream height during storm events. Coupled with the stage recorders, manual velocity measurements were taken at a variety of different stream stages to estimate a stream discharge with a known stage height. By establishing a stage-discharge relationship at the outlet of each sub-watershed, the AnnAGNPS model's predicted runoff was calibrated to the measured runoff seen at each sub-watershed per storm event. The AnnAGNPS model's predicted sediment yield was calibrated from several measured suspended solid concentrations collected during a variety of storm events, in each sub-watersheds' main channel, with a combination of Scientific Instruments, Inc. DH-48 Depth Integrated Sediment Sampler (Model 5200) and a set of Teledyne ISCO™ Automatic Portable Water Samplers (Model 6712).The DH-48 is a useful tool to manually obtain the total solids concentration within the stream while the ISCO samplers are programmed to take a series of water samples without human supervision. Grab samples from the unpaved roads were also obtained to better represent the amount of sediment entering into the streams from these features. All the sediment samples were analyzed to determine the total suspended solids concentrations as clays, silts, and sands. Once the AnnAGNPS pollutant model was satisfactorily calibrated for each sub-watershed, the model was used to compute an average annual sediment yield at specific depositional points where the fine bed sediment was collected. The particle size distribution characteristics of fine sediment were then statistically compared to the hillslope sediment yield produced by the AnnAGNPS pollutant loading model for the four sub-watersheds found in the New River Basin.

3.3 Stream Bed Sediment Characterization

3.3.1 Bed Sediment Collection

While conducting stream surveys and RGA documentation for each stream site in the New River Basin, a Garmin™ GPSMap 76 was used to record the coordinates of each site within five meters of accuracy. At each site, two methods were used to measure the bed sediment characterization: Modified Wolman Pebble Count (Wolman, 1954; Williams, 2005) and the collection of deposited bed sediment (Reid & Dunne, 1996; Williams, 2005). The Modified Wolman Pebble Count was used to determine the median stream bed diameter (D_{50}) and the stream bed diameter that is larger than 84% of the majority of the stream bed material (D_{84}).

Channel deposition points are hydraulic locations in the stream that have inconsistent velocities in comparison to the overall stream movement during average flow conditions. The fine sediment transported in the stream is deposited in point bars, side bars, or behind objects like large boulders in the stream that shield the natural flow during variations of stream discharge intensity. This study uses Williams's (2005) procedure for the collection of fine bed sediment at deposition points within the channel for particle size analysis. Williams (2005) states that the most diverse sediment samples are found from point bars, but if a point bar is not found near the stream reach, a side bar is the next depositional point where representative samples are most likely to occur. Finally, if a point bar or side bar cannot be located near the stream reach for a suitable sediment sample, depositional points behind large object (boulders and logs) within the stream that interrupt the flow should be used. The sediment accumulation behind objects in the stream is usually small and a large sample with one scoop may be a difficult task. All three deposition points mentioned above should contain similar proportions of fine sediment accumulations transported in the stream during high flow periods (Reid & Dunne, 1996; Williams, 2005). Every stream site is unusual and will contain different hydraulic characteristics. Most bed sediment samples collected within the different sub-watersheds in the New River basin were found on side bars and behind large objects within the stream.

The collected bed sediment was obtained during from February through September of 2007 using a modified McNeil stainless steel sediment sampler (shown in Figure 8) that is 20.2-cm long and has an inside diameter of 7.1-cm (McNeil & Ahnell, 1960; Williams, 2005). The McNeil sampler has been shown to obtain a consistent and accurate estimate for bed composition in streams (Young et al., 1991). For every stream site, the stainless steel sediment sampler was used to scoop up a representative sediment distribution from a depositional point in the stream reach with one single scoop. In order to not lose any fine material, the mouth of the sediment sampler was oriented to face the upstream flow of the stream. Once the material from the sediment sampler was acquired, the fine sediments (and usually water from the stream) were carefully poured into a plastic container with the Rapid Geomorphic Assessment (RGA) site and date marked. All sediment particles that remained in the sediment sampler after the initial dispense were carefully rinsed so as to not affect future samples.

3.3.2 Fine Bed Sediment Particle Size Distribution

The bed sediment captured at different stream sites was then taken to the Civil Engineering Geotechnical Laboratory at the University of Tennessee, Knoxville. At the laboratory, the bed sediment was characterized through a Dry Sieve Analysis and the Hydrometer Analysis to define the particle size distribution of each sample in accordance with the standard procedures for the test method of particle-size analysis of soils (ASTM

Figure 8: Modified McNeil Sediment Sampler.

D, 422-63). The Dry Sieve Analysis found the amount of sediment between a sieve #4 through #200 (4.75 mm – 0.075 mm), which defines the amounts of gravels and coarser sand particles. By incorporating the Hydrometer Analysis, the principles of Stokes Law (spherical particle falls at a constant velocity by equilibrium of its weight, drag forces, and buoyancy forces) can provide an estimate of the amount of sediment particles between 0.038 mm to 0.001 mm. Therefore, the Hydrometer Analysis is useful in defining the amount of silts and clays in the captured bed sediment.

The results of the Dry Sieve and Hydrometer Analysis were combined to collectively estimate the amount of gravel, sand, silt, and clays represented in each sediment sample. Provided in Figure 9, there are various standards that classify the particle sizes into sands, silts, and clays. Since the stream bed sediment samples collected were to be compared to the hillslope sediment yield in the AnnAGNPS model output, it was important that the particle size classification of bed sediment results matched that of the program, which is based on the USDA particle size classifications. Since the AnnAGNPS pollutant loading model was created by the USDA, the computer obviously

United States Department of Agriculture	CLAY	SILT	SAND					GRAVEL
			Very Fine	Fine	Med.	Coarse	Very Coarse	
	0.002	0.05	0.1	0.25	0.5	1.0	2.0	mm

International Society of Soil Science	CLAY	SILT	SAND		GRAVEL
			Fine	Coarse	
	0.002	0.02	0.2	2.0	mm

United States Public Roads Administration	CLAY	SILT	SAND		GRAVEL
			Fine	Coarse	
	0.005	0.05	0.25	2.0	mm

Figure 9: Common particle-size classifications (Brady, 1974; Haan, 1994).

uses the USDA's size classifications of clays, silts, sands, and gravels. As that seen in Table 2, the particle size and characteristics that are used within the AnnAGNPS pollutant loading model for sediment yield are a simplified version of the USDA's particle size classification by not having different sub-classifications of sands. Also notice that in Table 2, the small and large aggregate sizes that encompass both silts and sands were not used in this study but are provided to show that the AnnAGNPS program contains five different particle size parameters.

Another parameter that was analyzed with the classifications of clays, silts, sands, and gravels was the individual slopes of the percent finer particle size distribution curves for the clays, silts, sands, and gravels. The clay, silt, sand, and gravel slopes from the percent finer particle size distribution curves for all stream bed sediment samples were summarized and evaluated statistically with the hillslope sediment yield predicted from the AnnAGNPS model. The individual slopes of clays, silts, sands, and gravel for each particle size distribution curve is another technique to classify the quantity of sediment

Table 2: Sediment particle-size classification in AnnAGNPS (Young et al., 1987).

Particle-Size Classifications	Particle Size Range (mm)	γ_D Particle Density (Mg/m3)	$\mathbf{V_f}$ Fall Velocity (mm/s)	**k** Transport Capacity Factor (---)	D_p Equivalent Sand Size (mm)
Clay	< 0.002	2.60	3.11E-03	6.34E-03	2.00E-03
Silt	0.002 - 0.050	2.65	8.02E-02	6.05E-03	1.00E-02
Sand	0.050 - 2.000	2.65	2.31E+01	6.05E-03	2.00E-01
Small Aggregates	0.020 - 0.075	1.80	3.81E-01	1.25E-02	3.51E-02
Large Aggregates	0.200 - 1.000	1.60	1.65E+01	1.66E-02	5.00E-01

found in the stream bed (Williams, 2005).

3.4 AnnAGNPS Model Input Requirements

The AnnAGNPS pollutant loading model required a substantial amount of empirical data to correctly predict the hydrological and sediment-based elements occurring within a watershed. A brief summary table (Table 3) is shown to provide the sources of information used for the AnnAGNPS pollutant loading model with this study. Within the next sections are more details about the information used within the AnnAGNPS model.

3.4.1 Land Use

The land use/land cover data for the AnnAGNPS pollutant loading model was

Table 3: Summary of data sources used in the AnnAGNPS model.

AnnAGNPS Required Data	Source of Data
Soils	Tabular & Spatial files from USDA-NRCS (Nashville District)
Land Use	General land use base map from USGS - Seamless Data Distribution System
	Updated/Modified with DOI-OSM Active & Abandoned Surface Mining Permitted Areas
	Updated/Modified with TWRA Forest Logging Permitted Areas
	Updated/Modified with USGS, DOI-OSM, & TWRA Haul Roads, Dirt Roads, & Trail Maps
	Updated/Modified with DOI-OSM 2006 Raster Images of the New River Basin
DEM	10-Meter Resolution Quad Maps provided by USGS & DOI-OSM
Climate	Full weather station used at the Big South Fork River & Recreation Area maintained by MesoWest
	Precipitation data for each sub-watershed was modified with 4-NOAA tipping bucket rain gauges maintained by DOI-OSM

obtained from several sources. Initially, the land use/land cover GIS shapefiles for the four sub-watersheds were obtained from the USGS Seamless Data Distribution System (http://seamless.usgs.gov/), but a noticeable difference from the 2001 USGS land use/land cover and actual conditions from field reconnaissance indicated that more information was required for an accurate analysis. The U.S. Department of the Interior – Office of Surface Mining (OSM) generously provided a recent (2006) USGS Land Cover GIS shapefile with recent logging (from local Tennessee Wildlife Resource Agency (TWRA) personnel) and surface mining GIS shapefiles, which defined disturbed areas not found on the USGS land use/land cover maps. OSM also provided aerial photographs taken in years 2005-2007 that were used to better classify current logging and surface mining activities. From the combination of GIS data from USGS, OSM, TWRA, and slight modifications to all of these files to match recent aerial and field maps of the area, the land use/land cover GIS map of the four sub-watersheds of interest in the New River Basin were created for the AnnAGNPS-ArcView Interface. Each cell contained an attribute table that specifically defined the spatial land use/land cover patterns (previously summarized in Table 1) for hydrological computations. Figure 10 presents several polygons appended to the USGS land use GIS files which represent recent forest logging and surface mining activities in each New River sub-watershed used in this study. Found in Figure 10 are different polygons which represent different severities of logging (25%, 50%, 75%, and 100% logged areas) and surface mining (abandoned and active). The variations of green polygon outlines are for the four different classifications of logging while the red polygon outlines are for active and abandoned mining land uses. The

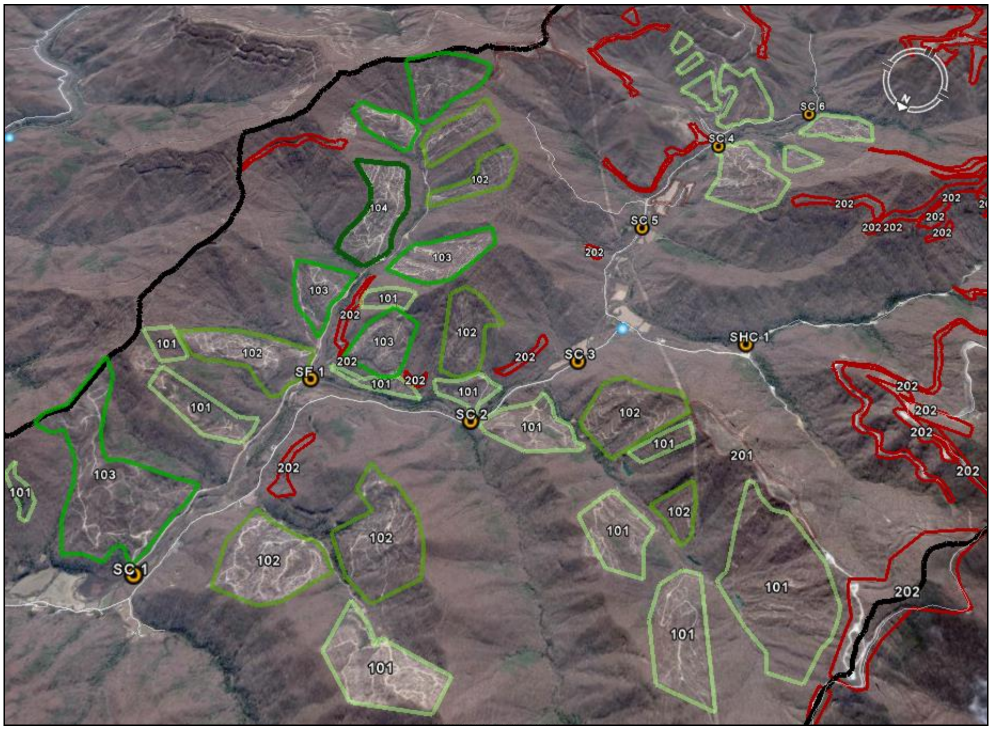


Figure 10: Example of land use polygons created for AnnAGNPS. (Aerial raster image taken from Google Earth, 2007)

numbers found inside each polygon are the different field identifications given to each land use. For areas that have 25%, 50%, 75%, and 100% logged, the associated field identification numbers are 101, 102, 103, and 104 respectively. Active mining has a field number of 201 while abandoned surface mined areas have are identified by the field number of 202.

<u>3.4.2 Soils</u>

The soil GIS shapefiles for the AnnAGNPS pollutant loading model were obtained from the USDA-NRCS Soil Data Mart (http://soildatamart.nrcs.usda.gov/). Once the GIS shapefiles of the different soil types are placed into the AnnAGNPS-ArcView Interface, a set of two National Soil Information System (NASIS) comma separated value (.csv) files must be loaded into the AnnAGNPS Input Editor to translate the graphical GIS shapefiles. The numerical soil information for the entire New River Basin was obtained by a state soil scientist with the USDA-NRCS office in Nashville, Tennessee. Initially the single NASIS soil file was sent as a text file (.txt) that contained all the soil information specifically for the use of AGNPS and AnnAGNPS models. The single NASIS soil text file had to be translated into two different comma separated value files to be imported into the AnnAGNPS model. The NASIS text file was sent to the National Sedimentation Laboratory for proper conversion of the data into two distinct comma separated value files for the AnnAGNPS model. The soil files (defined as soil_layer.csv and soil_dat.csv) were imported into the AnnAGNPS Input Editor to correctly match and identify the numerical tables of data with the polygons in the AnnAGNPS-ArcView GIS interface of USDA-NRCS soils in the four sub-watersheds in the New River Basin.

3.4.3 Topography

The topography of the four sub-watersheds of interest is represented by Digital Elevation Maps (DEMs). DEMs are a digital representation of topography maps and are useful for establishing a defined surface grid for computer simulations. Initially, a set of 30-meter resolution DEMs of the entire New River Basin was obtained through the USGS Seamless Data Distribution System. To increase the accuracy of the AnnAGNPS model, a better resolution of the area was suggested. With the help of the local OSM office in Knoxville, Tennessee, a 10-meter resolution display of the New River Basin in defined quad maps was provided for the analysis. After merging several 10-meter DEMs with the AnnAGNPS-ArcView Interface, a single DEM grid for the area of interest in the New River Basin was created and used for the AnnAGNPS modeling in this study.

3.4.4 Climate

The climate of the four sub-watersheds of interest in the New River Basin is represented from the data measured by a weather station found at the Big South Fork River and Recreation Area in Scott County, Tennessee. The location of this weather station sits at an elevation of 440.5 meters and is found at UTM latitude and longitude coordinates of 36.4750-N and 84.6542-W, respectively. The local weather station has been collecting data since 2003 through the MesoWest (University of Utah – Mountain Meteorology Group). For proper calibration of the AnnAGNPS pollutant loading model, a simulation period of four years (2005-2008) was selected to establish average annual erosion and sediment yield values for each of the four sub-watersheds in the New River Basin. Real weather data was placed into the AnnAGNPS pollutant loading model during 2005-2008. The program was initialized with normal historical climatic observations for the specific location of the New River Basin. Principally, the model's results during years 2007 and 2008 were compared with measured runoff and suspended sediment. From the weather station, the maximum temperature, minimum temperature, dew point, wind speed, and solar radiation were summarized in daily values from January 1, 2005 to March 7, 2008.

Since precipitation data is one of the most critical sources of information for a calibrated AnnAGNPS pollutant loading model, four additional precipitation gauges were used in the surrounding New River Basin to better estimate the specific precipitation at each sub-watershed. The additional precipitation gauge information was provided through the Automated Flood Warning System (AFWS) managed by the National Weather Service. These tipping bucket rain gauges are located at Buffalo Mountain, Cross Mountain, Walnut Mountain, and Adkins Mountain. The precipitation values for each station were weighted with the Big South Fork Weather Station (based on location and elevation) to determine an overall estimate of daily precipitation for each sub-watershed for calibration purposes.

For the size and the mountainous terrain of the sub-watersheds found in the New River Basin, more climate measuring devices should be strategically placed to produce the best results with the AnnAGNPS pollutant loading model. Due to a lack of financial resources, personnel, and time associated with this study, the climate data used in the AnnAGNPS pollutant loading model was obtained from existing weather stations remotely close to the four sub-watersheds.

3.5 AnnAGNPS Land Use Characteristics

To establish the an accurate simulation in the AnnAGNPS program, the watershed storm type, the 2-year 24-hour precipitation amount, the rainfall factor (R-factor), the ten-year frequency storm erosivity value (EI_{10}), and the storm erosivity (EI) distribution zone for the U.S. must be properly defined for each sub-watershed hydrologically simulated.

Using the Appendix B of the *NRCS TR-55 Urban Hydrology for Small Watersheds* manual, the four sub-watersheds of the New River Basin fall into the Type II Rainfall Distribution as shown in Figure 11. The Appendix B of the *NRCS TR-55 Urban*

Hydrology for Small Watersheds manual is also used to estimate the 2-year 24-hour precipitation amount of the New River Basin, which is approximately 83 mm (3.25 inches). Figure 12 presents the NRCS TR-55 map of the 2-year 24-hour precipitation for the entire U.S.

Using the isoerodent map of the eastern United States from the *USDA-ARS Agriculture Handbook Number 703 - Predicting Soil Erosion by Water: A Guide toConservation Planning with the Revised Universal Soil Loss Equation (RUSLE)*, the R-factor is estimated to be 3,320 MJ-mm / ha-hr-yr (195 ft-tonsf-in / acre-hr-yr), the EI_{10} value is estimated to be 1362 MJ-mm / ha-hr (80 ft-tonsf-in / acre-hr), and an EI distribution zone of 109 for all sub-watersheds is found within the New River Basin. The graphical maps used from the *USDA-ARS Agriculture Handbook Number 703* to obtain

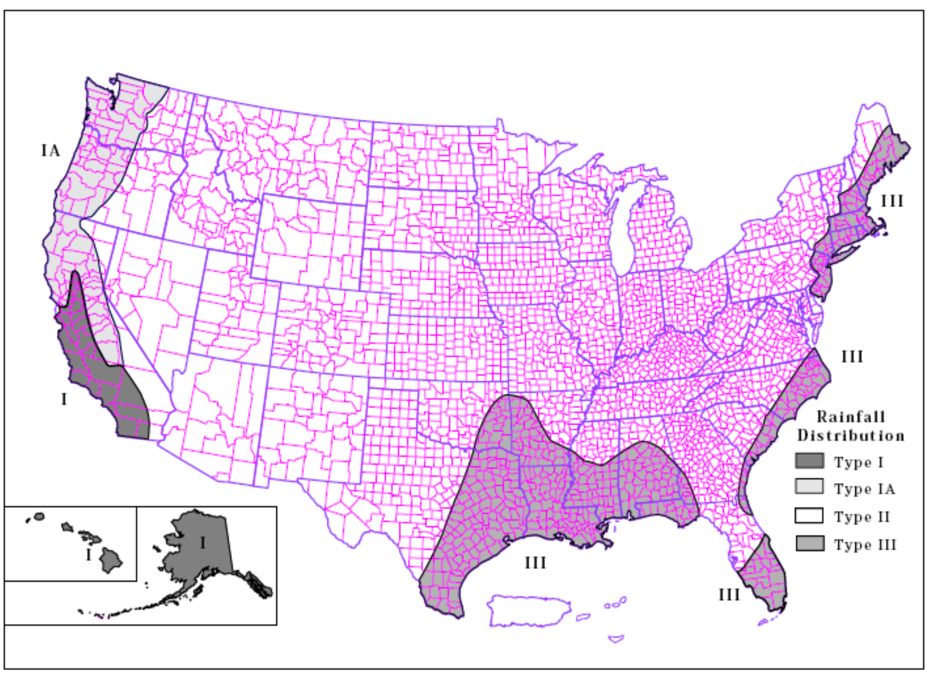


Figure 11: Geographical boundaries for NRCS (SCS) rainfall distributions (USDA, 1986).

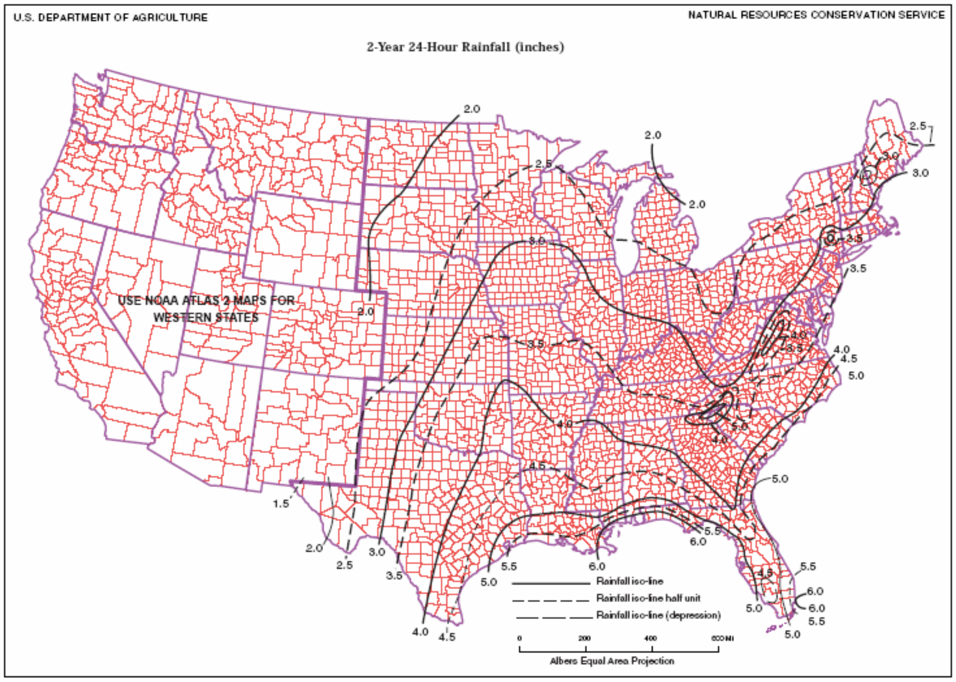


Figure 12: Approximate values of the 2-year 24-hour rainfall for the U.S. (USDA, 1986).

the R, EI_{10}, and EI distribution zone for the four sub-watersheds in the New River Basin are found in Figures 13-15.

The AnnAGNPS model uses the SCS Runoff Curve Method found the in the *NRCS TR-55 Urban Hydrology for Small Watersheds*. The SCS Runoff Curve Number (CN) calculations are used to estimate the overland and subsurface flow of storm water for different land use/land cover as well as specific soil types. The general SCS runoff equation (USDA, 1986) is defined as

$$Q = \frac{[P - I_a]^2}{[P - I_a] + S} \tag{1}$$

where,

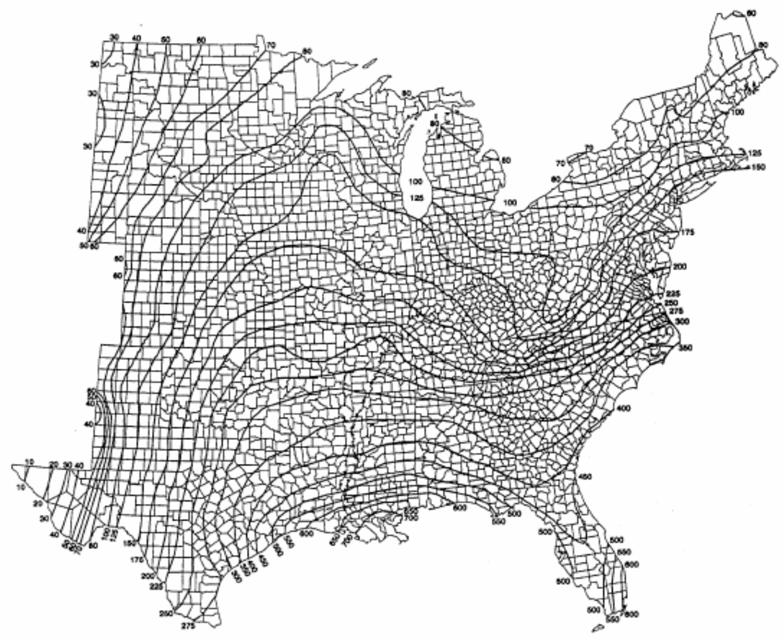


Figure 13: Isolines of annual R factor for the Eastern U.S., units in ft-tonsf-in / acre-hr-yr (Renard et al., 1997).

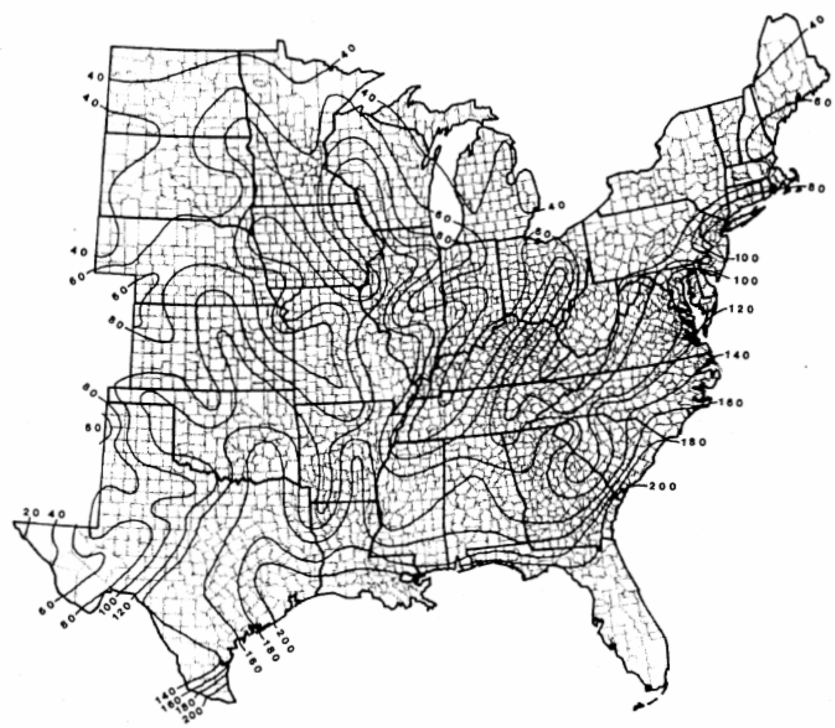


Figure 14: Ten year frequency single-storm erosivity values for the Eastern U.S., units in ft-tonsf-in / acre-hr (Renard et al., 1997).

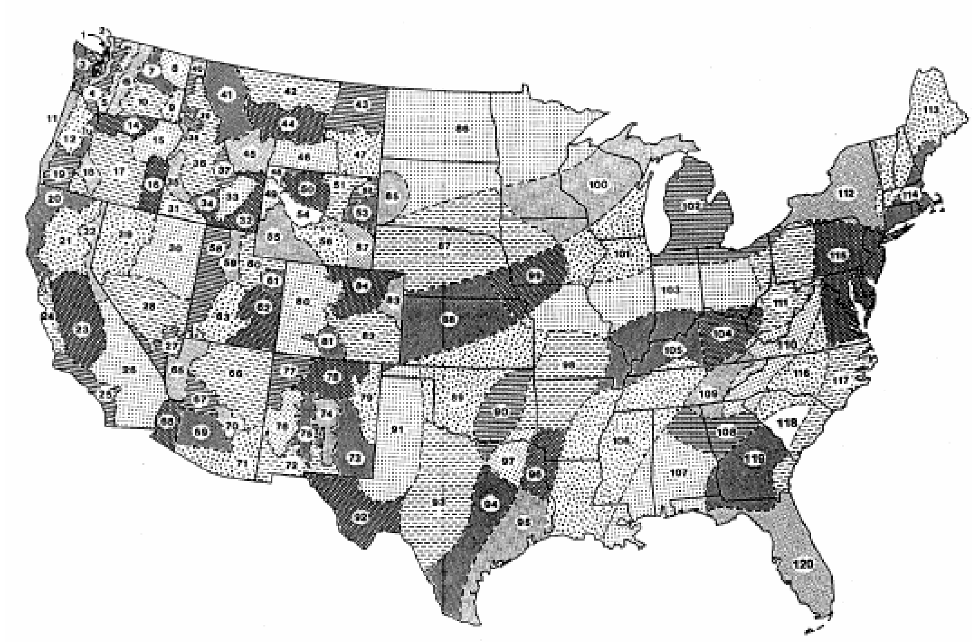


Figure 15: EI distribution zones for contiguous U.S. (Renard et al., 1997).

Q = runoff (mm)

P = rainfall (mm)

S = potential maximum retention after runoff begins (mm)

I_a = initial abstraction (mm)

The soil retention variable (S) after runoff begins is largely based on the CN value assigned to a land use and its hydrologic soil group. Largely, the S variable, which defines the amount of the soil's retention ability, is what is used by the AnnAGNPS model to calculate the amount of storm water runoff. As seen in the equation below, S (mm) can be determined by the Runoff Curve Number (CN) defined for certain land uses and soils (USDA, 1986).

$$S = 254\left(\frac{100}{CN} - 1\right) \tag{2}$$

The initial abstraction (I_a) variable accounts for the hydrological losses before runoff begins, which includes water retained in surface depressions, interception, evapotranspiration, and infiltration. The I_a variable is determined from the soil's retention value (S) shown in the equation below (USDA, 1986).

$$I_a = 0.2S \tag{3}$$

As seen in the initial abstraction equation above, the I_a is only 20% of the soil's retention value (S). This 20% of the soil's retention value for the initial abstraction comes from a collaboration of many studies in small agricultural watersheds (USDA, 1986). For the AnnAGNPS model, there will not be any storm water runoff generated if the daily precipitation value is less than the initial abstraction value.

Within the AnnAGNPS Input Editor, each land use/land cover defined in the sub-watersheds contains many hydrological variables to better calculate runoff, erosion, and sediment yield. Initially, the CN for the hydrologic soil groups for each land use found in the four sub-watersheds were selected from the *NRCS TR-55 Urban Hydrology for Small Watersheds* handbook, suggestions from AGNPS User Manual, and previous AnnAGNPS models used by personnel at the USDA National Sedimentation Laboratory. The CN values were slightly adjusted to better calibrate the AnnAGNPS model's land use activities with runoff and sediment yield. The CN values are not just dependant on land use alone; they are also defined by the hydrologic soil group for the same area for a single land use activity. The hydrologic soil group classifications (A, B, C, and D) are used in conjunction with land use activities to define the natural infiltration rate of the soil, which relates to amount of surface runoff per storm event.

Similar to the rainfall-runoff computations of the NRCS TR-55 model, the AnnAGNPS pollutant loading model uses typical Manning's n values for sheet, shallow concentrated, and channel flow to account for the roughness and drag of storm water transported throughout different land use environments. The Manning's n values are individually inserted into designated cells and reaches, by the user, within a watershed in the AnnAGNPS model. Typical Manning's n values for sheet flow, based on different land use classifications can be found in the *NRCS TR-55 Urban Hydrology for Small Watersheds* handbook. For the AnnAGNPS pollutant loading model, the shallow concentrated flow Manning's n values are provided for either disturbed or non-disturbed areas, which are 0.05 and 0.025 respectively. The Manning's n values for channel flow conditions are defined for the reaches that connect cells of area in a watershed. Each reach can have a specific Manning's n value for open channel flow if desired, but the AnnAGNPS model automatically designates a general 0.04 value to each reach otherwise. For this study, Manning's n values were defined through calibration techniques for sheet, shallow, and concentrated flow within each cell and reach based on the dominate land use determined.

The next set of calibration parameters within the AnnAGNPS model is through the RUSLE (version 1.05) calculations. The RUSLE equation is primarily used for estimating average annual sheet and rill erosion, in terms of mega-grams (Mg) or metric ton (t) per area. The RUSLE equation can be seen below (Renard et al., 1997).

$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P \tag{4}$$

where,

A = average annual erosion rate (Mg / ha or t / ha)

R = rainfall-runoff erosivity factor (MJ mm / ha h)

K = soil erodibility factor (t ha h / ha MJ mm)

LS = topography factor (m/m)

C = cover management factor (dimensionless)

P = support practice factor (dimensionless)

Next, the RUSLE R-factor was estimated by use of the isoerodent map of the U.S. from the *USDA-ARS Agriculture Handbook Number 703*. This value is manually typed into the AnnAGNPS Input Editor from the location of the area of interest. The K-factor is an integration of the impacts of rainfall and runoff causing erosion on a plot of soil and is calculated in the AnnAGNPS model based on the soil properties entered for the watershed. The K-factor has historically been estimated by the use of nomographs. The analytical relationship of the nomograph is found in the following equation (Wischimeier et al., 1971).

$$K = \frac{\left(2.1 \times 10^{-4}\right)\left(12 - OM\right)\left(M^{1.14}\right) + 3.25\left(S_1 - 2\right) + 2.5\left(P_1 - 3\right)}{100} \tag{5}$$

where,

K = soil erodibility factor (t ha h / ha MJ mm)

OM = percentage of organic matter (%)

M = primary particle size fractions (%)

S_1 = soil structure (1-4 based on soil characteristics)

P_1 = soil permeability (1-6 based soil drainage rate)

For the K-factor to be calculated, the primary particle size fraction function (M) is determined based on the percentages of silts (MS), very fine sands (VFS), and clays (CL) in the following equation (Hann et al., 1994).

$$M = (MS + VFS)(100 - CL) \quad (6)$$

Another RUSLE parameter required in the AnnAGNPS program is the LS-factor. The LS-factor is estimated from the topographical elevations defined by the DEM's in the GIS interface for the AnnAGNPS pollutant model for defined cells in the watershed.

One of the RUSLE parameters within the AnnAGNPS model to be used in the calibration process is the relationship of the different land use values with the RUSLE Cover-Management Factor (C-Factor). The C-factor can be broken into several sub-factors: Prior-Land Use (PLU), Canopy-Cover (CC), Surface-Cover (SC), Surface-Roughness (SR), and Surface-Moisture (SM). Using these sub-factors, a soil loss ratio can be determined using the following equation (Renard et al., 1997).

$$SLR = PLU \cdot CC \cdot SC \cdot SR \cdot SM \qquad (7)$$

From the soil loss ratio and an EI value for a certain period of time, the C-Factor can be computed using the following equation (Renard et al., 1997).

$$C = \frac{\left[(SLR_1)(EI_1) + (SLR_2)(EI_2) + ... + (SLR_n)(EI_n)\right]}{EI_t} \qquad (8)$$

where,

SLR_i = Soil loss ratio for time period i

EI_i = EI parameter for time period i

EI_t = Sum of the EI percentages for the entire time period

Thus, the program calculates the RUSLE C-Factor by analyzing multiple values seen in the Non-Crop Data Section of the AnnAGNPS Input Editor. The multiple sub-factors used to calculate the RUSLE C-Factor in AnnAGNPS are the initial annual root mass, cover ratio, rainfall height, and surface residue cover values, which are associated with each land use type. The initial values used for the defined land use classifications within the four sub-watersheds were estimated from AnnAGNPS simulations for sediment yield completed by Thames (2005), Simon et al. (2002), and Simon et al. (2004). Once the model accurately predicted the daily runoff, the RUSLE C sub-factors were adjusted till the model produced an accurate sediment yield from each sub-watershed.

Finally, the last parameter that is to be calibrated by the AnnAGNPS pollutant loading model is the Management Field data defined for each land use. The Management Field data for each land use consists of defining the percent rock cover, RUSLE sub P-factor, the type of erosion likely, and whether the land use is classified as cropland, urban, forest, pasture, or rangeland. Like that of the RUSLE C-factor values, the Management Field data parameters for each type of land use was initially estimated from AnnAGNPS models from the work of Thames (2005), Simon et al. (2002), and Simon et al. (2004). The final Management Field data parameters used in this study can be seen summarized in the results section of this report.

To check the initial parameters used for each land use description in the AnnAGNPS pollutant loading model for each of the four sub-watersheds found in the New River, storm water runoff and sediment yield from the program were matched with the stream discharge and suspended sediment measurements from specific storm events.

Just as the AnnAGNPS model uses the RUSLE equation to estimate the erosion for a defined plot of land, the following HUSLE equation is used to estimate the sediment yield from sheet and rill erosion from Theurer and Clark (1991).

$$S_y = 0.22Q^{0.68}{q_p}^{0.95}KLSCP \qquad (9)$$

where,

S_y = sediment yield (Mg / ha or t / ha)

Q = surface runoff volume (mm)

q_p = peak rate of surface runoff (mm / s)

K, L, S, C, P = RUSLE factors

Because RUSLE does not assume any deposition from sheet and rill erosion, AnnAGNPS uses HUSLE to create a delivery ratio to determine the amount of deposition occurring from the erosion and sediment yield for five separate soil particles sizes (clay, silt, sand, small and large aggregates) based on each particle's mass fall velocity (Bingner et al., 2003). The equation to estimate the sediment delivery ratio from an initial location in a cell at point "1" (time of concentration equal to zero) to a cell's outlet location at point "2" is shown in the following equation (Bingner et al., 2003).

$$D_r = \frac{S_{y2}}{S_{y1}} = 0.95\left(\frac{q_{p1}}{q_{p2}}\right) \tag{10}$$

where,

D_r = delivery ratio from location "1" to "2"

S_{y1} = sediment yield at location "1" (Mg / ha or t / ha)

S_{y2} = sediment yield at location "2" (Mg / ha or t / ha)

q_{p1} = peak rate of surface runoff at location "1" (mm/s)

q_{p2} = peak rate of surface runoff at location "2" (mm/s)

3.6 Measured Runoff

The actual storm water runoff for each of the four sub-watersheds was estimated through the combination of Global Water™ Stage Recorders (Model No. WL-16) located near the outlet of each sub-watershed with stream velocity measurements taken with a Marsh-McBirney™ Flo-mate Model 2000 Flowmeter. All four stage recorders were installed at each sub-watershed by November of 2007 and were set to read data continuously in 20-minute increments. By multiplying the stage height by the average velocity at a specific moment in time, a stage-discharge relationship for each of the four sub-watersheds was developed. Through the stage-discharge relationship developed for each sub-watershed, an estimated discharge could be established from the continuous stage recordings taken. For higher stage recordings, the in-stream velocities could not be measured with the flow-meters; therefore, the U.S. Army Corp HEC-RAS model was used to estimate higher stage and discharge measurements encountered for each of the four sub-watersheds. The HEC-RAS model used a section of channel cross-section surveys upstream and downstream of the stage recorders with a common set of Manning's n values for mountainous stream conditions as well as stage and velocity measurements previously observed.

Once stage-discharge relationships were summarized with the four different sub-watersheds, the data was organized to develop stream flow hydrographs. These hydrographs were then separated into surface runoff and base flow from the following empirical equation.

$$N = A^{0.2} \tag{11}$$

where N is equal to the number of days after which surface runoff ceases from the peak of the hydrograph and A is equal to the watershed's area in square miles (Linsley et al., 1982). Therefore, the line that separates the stream flow and base flow of the hydrograph is approximately equal to 1.75N for a precipitation event.

The method used to dissect the surface runoff from the base flow on the hydrograph for each sub-watershed is defined as a combination of the Fixed-Interval Method and the Sliding-Interval Method. The stream and base flow separation method used in this study provided a means to draw a straight, horizontal line at the base of the hydrograph from the time when precipitation began to the time of the hydrograph's peak. From the time of peak, the height of the hydrograph at a time of N days past the peak would be drawn horizontally back to the time of peak. The area between the stream and base flow, on a hydrograph, would approximately determine the runoff experienced per storm event. Therefore, the difference in base flow and stream flow over a period of time is calculated to be the surface runoff for each sub-watershed.

3.7 Total Suspended Solids Analysis

For at least eight different storm events from January to March of 2008, a set of suspended sediment was measured near the outlet of all four sub-watersheds within the New River Basin using a Scientific Instruments, Inc. DH-48 Depth Integrated Sediment Sampler (Model 5200) and Teledyne ISCO™ Automatic Portable Water Samplers (Model 6712). For several suspended sediment samples collected during recorded storm events, a Total Suspended Sediment (TSS) analysis was conducted in The University of Tennessee Environmental Engineering Laboratory in harmony with Standard Methods procedures (Eaton et al., 1995). To briefly describe the TSS procedure used for all the stream samples, a pre-washed, dried fiberglass filter with a 0.7 micro-meter pore size was weighed on the analytical balance before use. Next, the filter was placed in the Millipore Filtration Apparatus and the vacuum pump connected to the device was turned on. To obtain an accurate weight of solid material trapped by the 0.7 micro-meter filters, 50-mL of stream water (with a mixed concentration of clays, silts, and sands) was pipetted onto a pre-washed, dried filter attached to a Millipore Filtration Apparatus. Note that just before 50-mL of stream water was extracted, each sample was stirred vigorously till the suspended solids (clays, silts, and sands) became thoroughly mixed After the 50-mL of stream sample drained through the filter, the vacuum pump was turned off and the filtrate (solution that passes through the filter) from the initial solution was removed to estimate the dissolved solids concentration. After the suspended solids were trapped onto the filter, the vacuum pump was turned off and samples were removed with tweezers, placed in an aluminum dish, and placed in the oven to dry for one hour at 103 degrees Celsius. After each filter dried for one hour, the filters with a weight of suspended solids were transported to the desiccators to cool and were reweighed on the analytical balance.

The importance of the TSS results for each of the four sub-watersheds is to calibrate the RUSLE parameters, previously discussed in the AnnAGNPS program, to accurately predict sediment yield. Since it is assumed that a majority of the sediment yield is caused from hillslope disturbances, a small amount of the TSS found per site should be from channel erosion. The summarized TSS values obtained for this study are found within the results section of this analysis.

3.8 Incorporation of Dirt Roads

As observed during several field investigations into each of the four sub-watersheds, dirt roads seemed to contribute noticeable amount of sediment into the nearby streams. Many studies have reported a large amount of sediment entering stream from heavily used dirt roads in rural regions of the world. For example, Table 4 provides an example of how much sediment dirt roads contribute in a watershed. All the dirt and gravel road systems were drawn into the GIS land use shapefile used in the AnnAGNPS model to incorporate different land use activities into the flow cells. Since the AnnAGNPS model's grid of flow cells only accept the largest land use activity within the same area of each flow cell, the dirt road were never recognized since their polygons dominated such a small portion of each flow cell. Therefore, it was evident that the program had to recognize the dirt roads into its sediment budget analysis before any further calibration could be completed. Since AnnAGNPS does not provide a direct point source option for sediment, as it does for many other agriculturally based pollutants, the classical gully function was used to roughly estimate the annual sediment yield generated from dirt roads in the New River. From field observations, the dirt roads used for travel to logged areas, mined areas, and other locations, often contained drainage ditches and culverts that created gullies down to the local streams. From different storm events, grab samples were taken from a variety of different gullies, culverts, and drainage ditches carrying sediment from dirt roads in each sub-watershed. The suspended sediment samples taken from the roads were further analyzed with the hydraulic components of the road drainage ways to estimate the amount of flow and suspended sediment that was

Table 4: Erosion measurements on roads and paths (Reid & Dunne, 1996).

Location	Road use	Gravel Depth (cm)	Slope (%)	Average Rainfall (mm/yr)	Soil Texture[1]	Soil Loss Rate[2] tons/(ha-yr-cm)
Washington	Abandoned	30	9	3500	sd-cl-lm	0.004
North Carolina	Light	0	5	2000	?	0.8
North Carolina	Light	5	8	2000	cl	0.5-1.0
North Carolina	Light	5	10	2000	sd	0.8-1.6
North Carolina	Light	15	5	2000	sd	0.06-0.12
North Carolina	Light	15	6	2000	cl	0.3
Washington	Light	30	9	3500	sd-cl-lm	0.03
Machakos, Kenya	Moderate	0	4	900	?	0.4-0.9
Machakos, Kenya	Moderate	0	14	900	?	1.0-2.8
Shinyanga, Tazania	Moderate	0	?	800	?	0.4-0.9
Shinyanga, Tazania	Moderate	0	1	900	sd-lm	0.8
Shinyanga, Tazania	Moderate	0	3	900	sd	1.1-1.4
Shinyanga, Tazania	Moderate	0	3	800	sd	1
Washington	Moderate	30	9	3500	sd-cl-lm	0.4
North Carolina	Heavy	0	5	2000	?	2.3
North Carolina	Heavy	5	10	2000	sd	1.6
North Carolina	Heavy	5	8	2000	cl	2.4
North Carolina	Heavy	15	5	2000	sd	0.2
North Carolina	Heavy	15	6	2000	cl	1.6
Washington	Heavy	30	9	3500	sd-cl-lm	2.3

Notes:

[1] Soil texture abbreviations: cl = clay, lm = loam, sd = sand

[2] Values for soil loss rate are in tons/(ha-yr) per cm of rainfall

required by the classical gully command in AnnAGNPS. Finally, each cell in each sub-watershed contained a large percent of dirt roads (5,000 square meters or 5% of a cell's area) was identified in the classical gully command to better estimate the sediment yield occurring at each sub-watershed in the New River Basin.

3.9 AnnAGNPS Model Calibrations

3.9.1 Model Calibration with Runoff

Before the measured sediment yield for each sub-watershed could be used to calibrate the AnnAGNPS pollutant loading model, the CNs and the Manning's n roughness coefficients for each designated land use assigned within a watershed must produce a realistic runoff amount for historical precipitation recordings. The goal was to use a uniform set of CN and Manning's n values, which produced a predicted runoff value that resembled measured runoff amounts. The summarized CNs and Manning's n roughness coefficients for the dominant land uses in each of the four sub-watersheds are shown in the results section of this report.

3.9.2 Model Calibration with Sediment Yield

After the CNs and the Manning's n roughness coefficients were adjusted to better simulate actual runoff from precipitation events, the measured total suspended solids analysis for specific daily storm events, at the outlet of each sub-watershed, were used to adjust different RUSLE variables, as well as the Manning's n roughness coefficients for sheet, shallow, and concentrated flow within the AnnAGNPS model. Aside from the dominant land use classifications of the RUSLE C- and P- factors, which are manually adjusted for proper calibration of the model, the dirt roads, simulated through the classical gully command in AnnAGNPS, were also used to determine the overall sediment yield occurring in each sub-watershed for calibration purposes. The summarized AnnAGNPS parameters that were used to calibrate measured to predicted sediment yield can be found in the results section of this report.

3.10 Statistical Analysis

The JMP statistical software was used to compare the relationship and correlations between particle size parameters of stream bed sediment collected at specific channel deposition points with the average annual sediment yield characteristics produced by a calibrated AnnAGNPS pollutant loading model. The stream bed sediment properties analyzed consisted of the percentage of clays, silts, sands, and gravels as well as the slope of the grain size distribution plots for clays, silts, sands, and gravels. The AnnAGNPS annual average hillslope sediment yield properties, that were treated as predictor variables, were based on the percent of and total weight of clays, silts, sands, as well as the total sediment yield for 2006 and 2007. The statistical procedures used for the particle size distribution of stream bed sediment deposition and the AnnAGNPS hillslope sediment yield consisted of box plot, multivariate, and stepwise regression through a standard least squares analysis. These procedures were used to analyze different combinations of the stream bed sediment data to predict hillslope sediment yield properties that have previously been transported down to the point where samples were collected in the four sub-watersheds. The summarized statistical analysis of the fine stream bed sediment properties with the average annual hillslope sediment yield of the AnnAGNPS pollutant model are further discussed in the results section of this report.

Chapter 4: Results

4.1 Stream Bed Sediment Characterization

After collecting the fine stream bed sediment samples at specific channel deposition points, at each sub-watershed, the sediment size characteristics were analyzed by particle size distributions. The particle size distributions were created through dry sieve and hydrometer analysis methods. The summarized stream bed sediment for each sub-watershed is found in Tables 5 through 8. Each table provides the percentage of clays, silts, and sands found in each sediment sample for the four sub-watersheds of interest in the New River Basin. Also contained in the tables are the RGA scores at the stream reach as well as the D_{50} and D_{84} values from the Modified Wolman Pebble Counts. For all 33 stream sites where stream bed sediment was collected, the RGA scores ranged from 5.0 to 12.5. An RGA score less than 20.0 indicates that a stream reach is stable, therefore all of the streams reanalyzed in this study are not in a state of dis-equilibrium. Since the stream reaches in this study are shown to be stable, bank erosion is not a source of excessive sedimentation. Therefore, the RGA surveys found that many of the stream channels in the New River Basin encounter a greater part of sediment delivery from upland natural resource extraction and other land use activities and not from stream bank sources. The sediment properties found in the following tables (Tables 5 through 8) are further analyzed with the average annual sediment yield generated from the AnnAGNPS pollutant loading model to determine if a correlation exists between the fine stream bed sediment deposits and sediment yield from the hillslopes.

Table 5: Brimstone Creek bed sediment characterization. (2007)

Site ID (---)	Principle Watershed (---)	Channel RGA Score (0-36)	Pebble Count D50 (mm)	Pebble Count D84 (mm)	Dry Sieve & Hydrometer Results Clays (%)	Silts (%)	Sands (%)	Gravels (%)	Particle Size Distribution Slope Clay (decimal)	Silt (decimal)	Sand (decimal)	Gravel (decimal)
BSC-1	Brimstone	8.5	38.0	98.0	0.00	0.21	39.19	60.60	0.00	4.37	20.10	3.56
BSC-2	Brimstone	5.0	34.0	94.0	0.05	0.99	47.60	51.36	7.07	20.72	24.41	3.02
BSC-3	Brimstone	7.0	33.0	94.0	0.05	0.90	25.85	73.21	7.02	18.70	13.26	4.31
JOE-1	Brimstone	5.0	50.0	124.0	0.11	0.47	33.43	66.01	14.73	9.85	17.14	3.88
IC-1	Brimstone	5.5	42.0	88.0	0.00	0.17	26.94	72.89	0.00	3.53	13.82	4.29
Average		6.2	39.4	99.6	0.0	0.5	34.6	64.8				

Table 6: Montgomery Fork bed sediment characterization. (2007)

Site ID (---)	Principle Watershed (---)	Channel RGA Score (0-36)	Pebble Count D50 (mm)	Pebble Count D84 (mm)	Dry Sieve & Hydrometer Results Clays (%)	Silts (%)	Sands (%)	Gravels (%)	Particle Size Distribution Slope Clay (decimal)	Silt (decimal)	Sand (decimal)	Gravel (decimal)
MFCS-1	Montgomery	10.5	30.0	88.0	1.85	9.30	55.29	33.56	197.00	193.83	28.35	3.56
MFCS-10	Montgomery	10.0	24.0	49.0	0.07	1.04	45.61	53.27	10.43	21.76	23.39	3.13
RC-1	Montgomery	11.0	16.0	38.0	0.06	0.67	36.34	62.94	13.79	13.86	18.63	3.70
RC-2	Montgomery	12.5	14.0	34.0	0.04	0.15	12.21	87.60	8.50	3.18	6.26	5.15
RC-3	Montgomery	10.5	12.0	32.0	0.01	0.30	33.68	66.01	4.69	6.20	17.27	3.88
JC-1	Montgomery	7.0	24.0	50.0	0.03	0.07	22.82	77.07	3.74	1.55	11.70	4.53
JC-3	Montgomery	6.0	12.0	24.0	0.03	0.37	58.29	41.31	8.44	7.69	29.89	2.43
SB-1	Montgomery	9.0	25.0	107.0	0.30	0.53	20.46	78.71	44.75	11.02	10.49	4.63
MKC-1	Montgomery	8.0	38.0	114.0	0.05	0.32	48.69	50.94	6.50	6.70	24.97	3.00
PCC-1	Montgomery	10.0	34.0	87.0	0.11	1.21	48.31	50.37	9.64	25.29	24.77	2.96
WC-1	Montgomery	7.0	41.0	104.0	0.01	0.14	25.52	74.33	2.99	2.91	13.09	4.37
Average		9.2	24.5	66.1	0.2	1.3	37.0	61.5				

Table 7: Ligias Fork bed sediment characterization. (2007)

Site ID (---)	Principle Watershed (---)	Channel RGA Score (0-36)	Pebble Count D50 (mm)	Pebble Count D84 (mm)	Dry Sieve & Hydrometer Results				Particle Size Distribution Slope			
					Clays (%)	Silts (%)	Sands (%)	Gravels (%)	Clay (decimal)	Silt (decimal)	Sand (decimal)	Gravel (decimal)
LF-1	Ligias	8.5	46.0	88.0	0.09	0.93	44.11	54.87	11.51	19.40	22.62	3.23
LF-2	Ligias	9.0	44.0	87.0	0.02	0.09	86.98	12.92	0.66	1.79	44.60	0.76
LF-3	Ligias	7.5	34.0	178.0	0.06	0.44	39.97	59.52	13.09	9.10	20.50	3.50
LF-4	Ligias	9.0	45.0	110.0	0.05	0.17	23.99	75.79	11.10	3.47	12.30	4.46
LF-5	Ligias	12.0	49.0	104.0	0.01	0.22	41.44	58.33	1.65	4.69	21.25	3.43
LF-6	Ligias	7.0	60.0	170.0	0.00	0.02	26.03	73.95	0.40	0.41	13.35	4.35
LF-7	Ligias	n/a	n/a	n/a	0.13	0.43	23.87	75.58	20.26	8.90	12.24	4.45
GGB-1	Ligias	6.0	56.0	232.0	0.07	0.32	55.68	43.93	8.44	6.60	28.56	2.58
GGB-2	Ligias	8.5	38.0	118.0	0.06	1.50	28.57	69.88	18.48	31.20	14.65	4.11
Average		8.4	46.5	135.9	0.1	0.5	41.2	58.3				

Table 8: Smokey Creek bed sediment characterization. (2007)

Site ID (---)	Principle Watershed (---)	Channel RGA Score (0-36)	Pebble Count D50 (mm)	Pebble Count D84 (mm)	Dry Sieve & Hydrometer Results Clays (%)	Silts (%)	Sands (%)	Gravels (%)	Particle Size Distribution Slope Clay (decimal)	Silt (decimal)	Sand (decimal)	Gravel (decimal)
SC-1	Smokey	9.0	30.0	58.0	0.43	3.01	84.62	11.93	29.54	62.81	43.40	0.70
SC-2	Smokey	9.0	40.0	96.0	0.04	0.23	33.66	66.07	3.61	4.80	17.26	3.89
SC-3	Smokey	8.0	38.0	96.0	0.02	0.33	43.10	56.55	5.21	6.88	22.10	3.33
SC-4	Smokey	9.5	46.0	102.0	0.03	0.39	54.67	44.90	0.00	8.20	28.04	2.64
SC-5	Smokey	9.0	34.0	74.0	0.01	0.15	29.91	69.93	1.82	3.14	15.34	4.11
SC-6	Smokey	10.0	45.0	112.0	0.13	1.45	50.13	48.29	18.18	30.17	25.71	2.84
SHC-1	Smokey	9.0	39.0	94.0	0.03	0.09	17.12	82.76	6.58	1.81	8.78	4.87
SF-1	Smokey	8.5	45.0	104.0	0.09	1.00	65.55	33.36	17.50	20.87	33.61	1.96
Average		9.0	39.6	92.0	0.1	0.8	47.3	51.7				

4.2 Total Suspended Solids Analysis

For at least eight different runoff events from January to March of 2008, a collection of suspended solids at the outlets of each of the four sub-watersheds was acquired to perform a TSS analysis on the samples. The TSS analysis was conducted to determine an estimated concentration of sediment yield occurring for each sub-watershed during a storm event.

The TSS values are commonly reported in mg/L (ppm) where as AnnAGNPS reports the sediment yield in Mg/day, where Mg is equal to a mega-gram or metric ton. To convert the TSS values in order to calibrate the AnnAGNPS pollutant loading model, the average TSS values for a precipitation event are multiplied by the runoff volume for a specific day to obtain a daily weight of sediment yield. After converting the measured TSS in terms of mega-gram per day (Mg/day), the predicted sediment yield produced by the AnnAGNPS pollutant loading model could be properly calibrated.

To account for the sediment yield generated by the dirt roads in the four sub-watersheds, a set of seven grab samples was taken from gullies, ditches, and culverts that routed storm water off of the roadways during February and March of 2008. These runoff grab samples were used to obtain a TSS concentration of sediment yield from the dirt roads from a random selection of heavily used unpaved roads found in each of the four sub-watersheds of the New River Basin. Since the AnnAGNPS model would not simulate dirt road land use features for runoff and sediment yield simulations, the classical gully command was used to produce a predicted sediment yield from the dirt roads in each of the four sub-watersheds. To use the classical gully command in AnnAGNPS, each flow cell had to be individually assessed, and only the flow cells that contained over 0.5 hectares of dirt roads or 5% of a cell's area dominated by dirt roads were be considered.

4.3 AnnAGNPS Model Calibrations

4.3.1 Flow Cell and Reach Generation

Before calibrating the AnnAGNPS model for each sub-watershed, the flow cells were adequately sized to represent the different types of land use activities and soil types within the area. For each sub-watershed, the CSA and MSCL were set to 15 hectares and 100 meters, respectively. Any smaller set of flow cell values in the AnnAGNPS model would either produce a list of errors or would group the same amount of land use and soil aspects of the area as before but require a longer time to compute more cell shapes. With the uniform set of flow cells defined, the location of the stage recorder (near the outlet of each sub-watershed) was set as the outlet of the system, and the various land use and soil type polygons created from the ArcMap GIS software were grouped into different flow cells for AnnAGNPS hydrologic computations. After the flow cell polygons are created, the AnnAGNPS model selects the dominant land use and soil type within a cell's area; therefore, each cell is entirely represented by a single land use activity and soil type. Figures 16 through 19 show the original land use types in a watershed before and after the cells capture the most dominant land use activities. Figures 16 through 19 have been divided into two segments: segment (a) and segment (b). For each figure, segment (a) illustrates the 2006 custom land use for each sub-watershed imported into the AnnAGNPS model, and segment (b) illustrates the dominant land use types for each

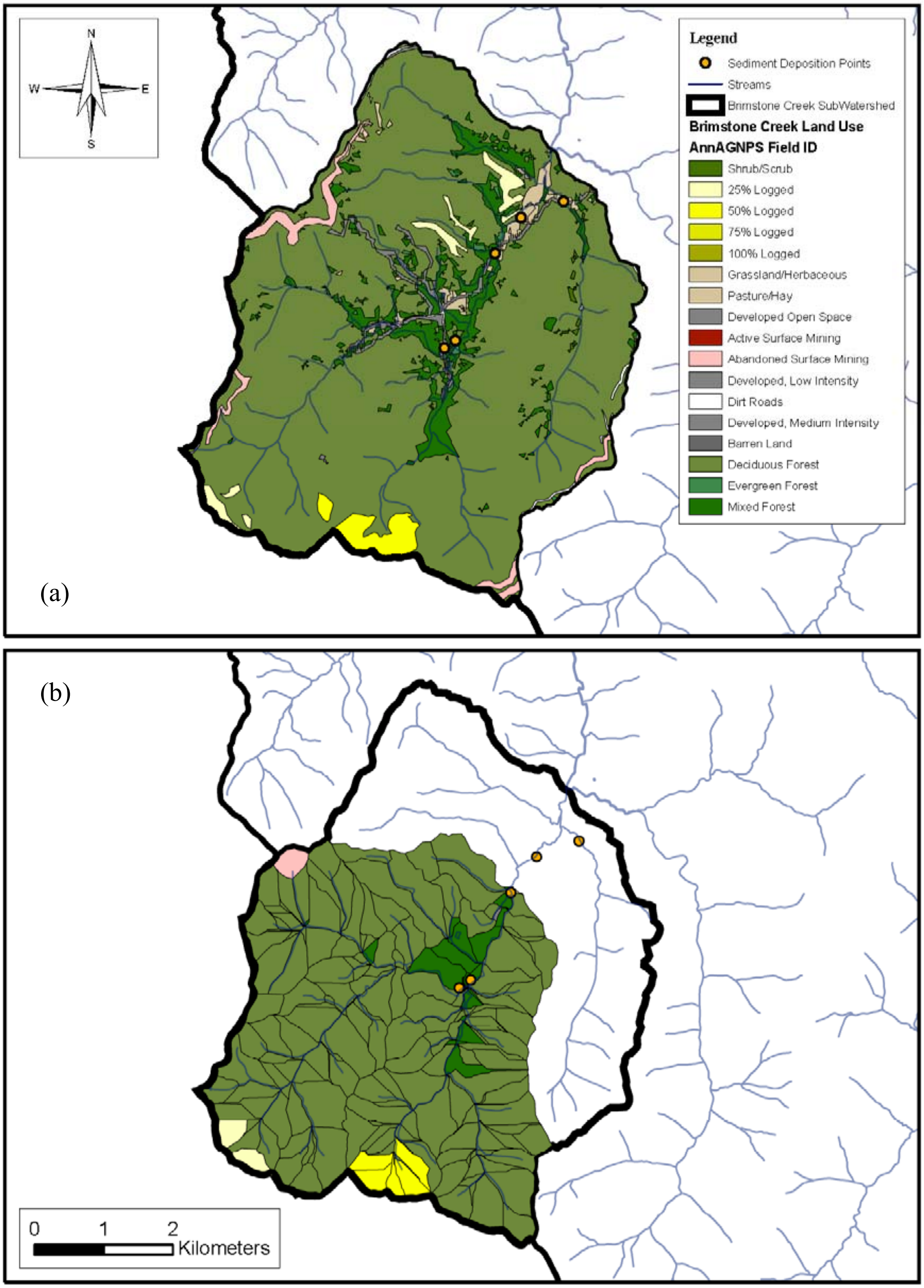


Figure 16: Brimstone Creek AnnAGNPS land use characterization. (2006)

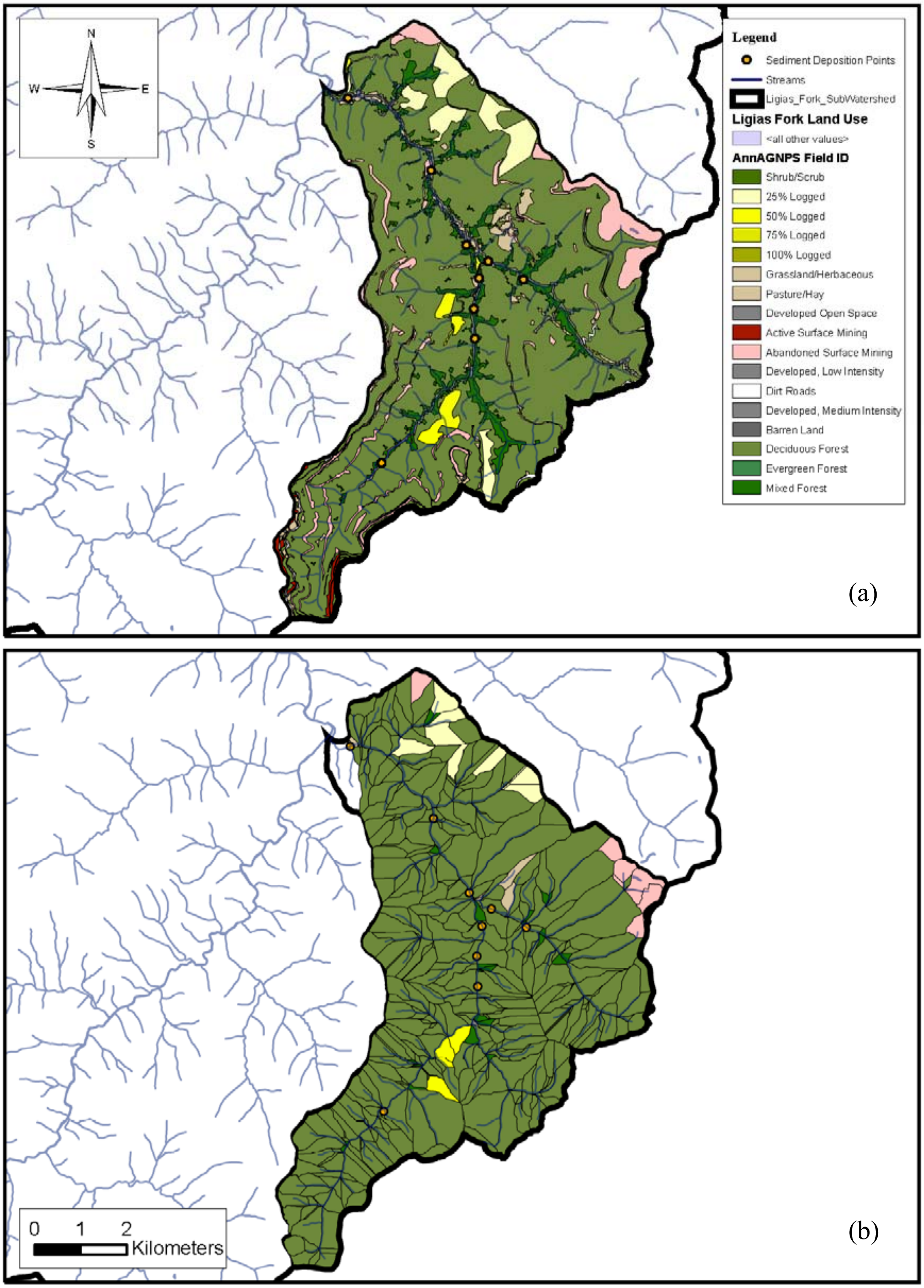


Figure 17: Ligias Fork AnnAGNPS land use characterization. (2006)

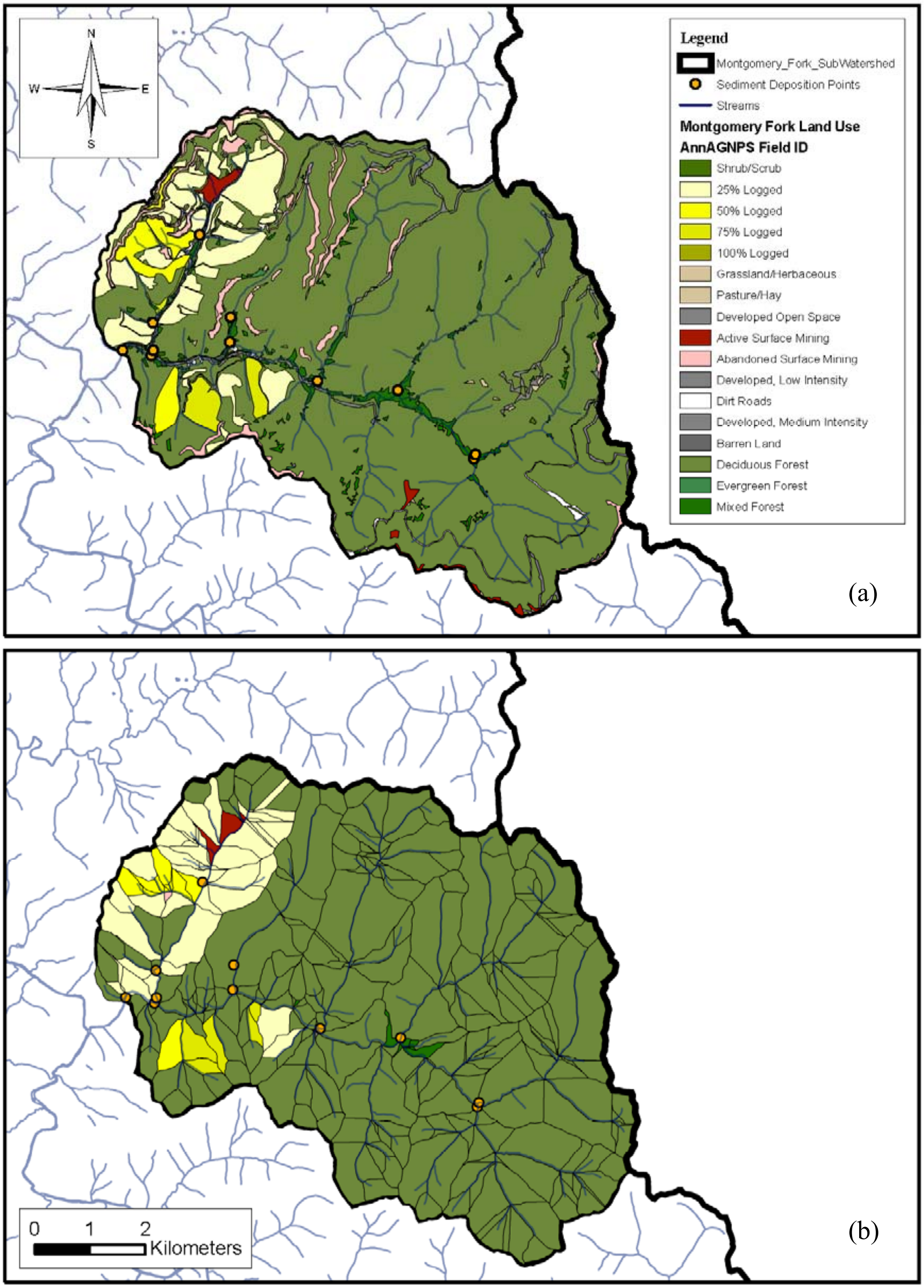


Figure 18: Montgomery Fork AnnAGNPS land use characterization. (2006)

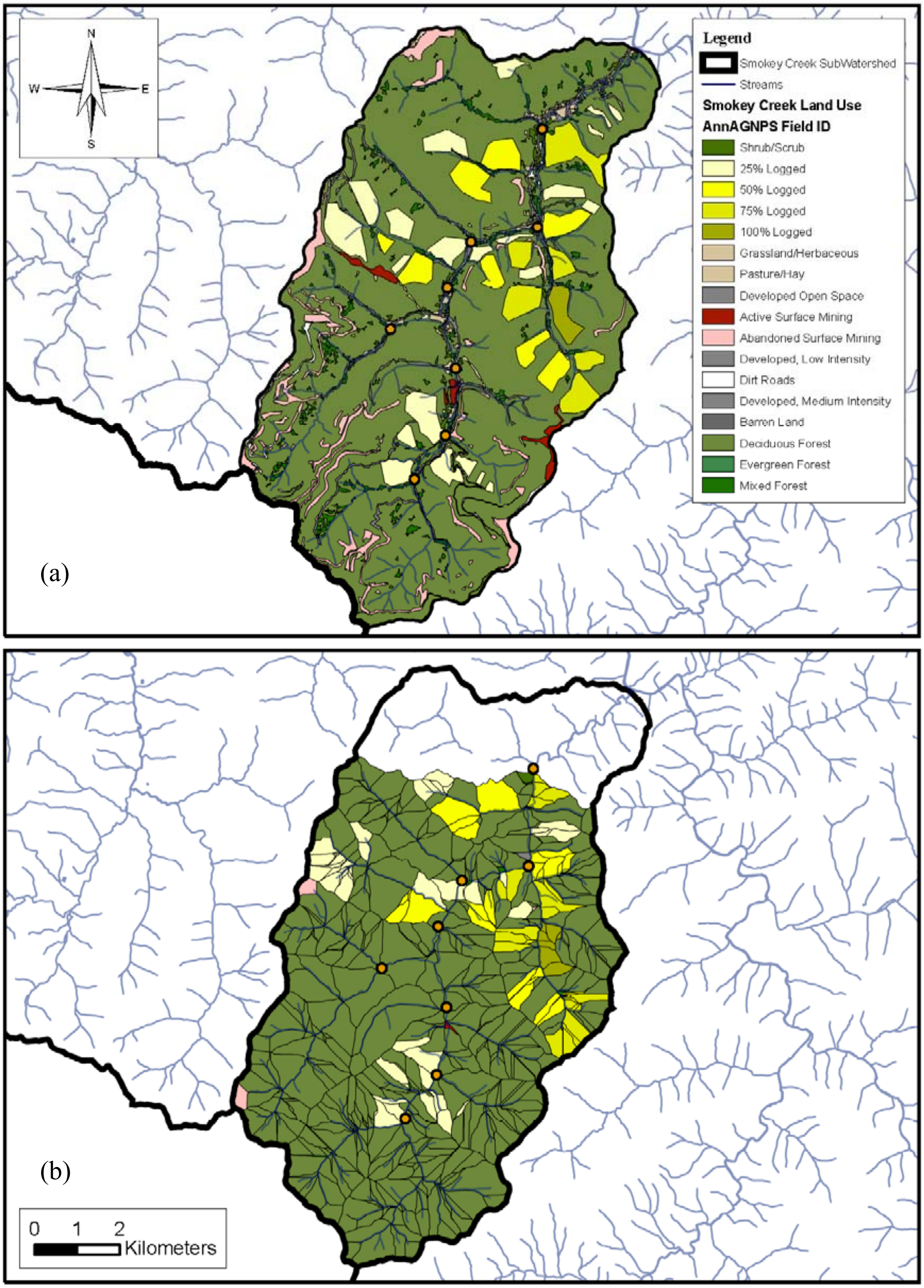


Figure 19: Smokey Creek AnnAGNPS land use characterization. (2006)

flow cell that the AnnAGNPS model uses for runoff and sediment yield computations. As seen in Figures 16 through 19, the AnnAGNPS pollutant loading model's flow cells only perform computations on a few of the land use activities that are largely found within each sub-watershed in the New River Basin.

Figures 20 through 23 show the original soil types within a watershed before and after the cells attempt to capture the most dominant soils within the area. Like that of each sub-watershed's land use previously mentioned, Figures 20 through 23 have been divided into two segments, a segment (a) and a segment (b). For each figure, the segment (a) is provided to illustrate the soil data for each sub-watershed imported into the AnnAGNPS model. Segment (b) of each figure is provided to illustrate the dominant types for each flow cell that the AnnAGNPS model uses for runoff and sediment yield computations. As seen in Figures 20 through 23, the AnnAGNPS pollutant loading model's flow cells only select the dominant soil types within each sub-watershed. The flow cells are largely created by the different topography of a watershed, and with such a steep terrain in the New River, several flow cells vary considerably in size.

4.3.2 Runoff Calibration

The measured storm water runoff at the outlet of each sub-watershed was measured by the coupled use of stream stage monitors set to record in 20-minute increments with manual velocity measurements taken at a variety of different stream stage heights. During several of the large storm events, the four sub-watersheds' stream velocity could not be safely measured, so the HEC-RAS model was used to estimate the stream discharge at stream stages that would present bankfull conditions or better. By

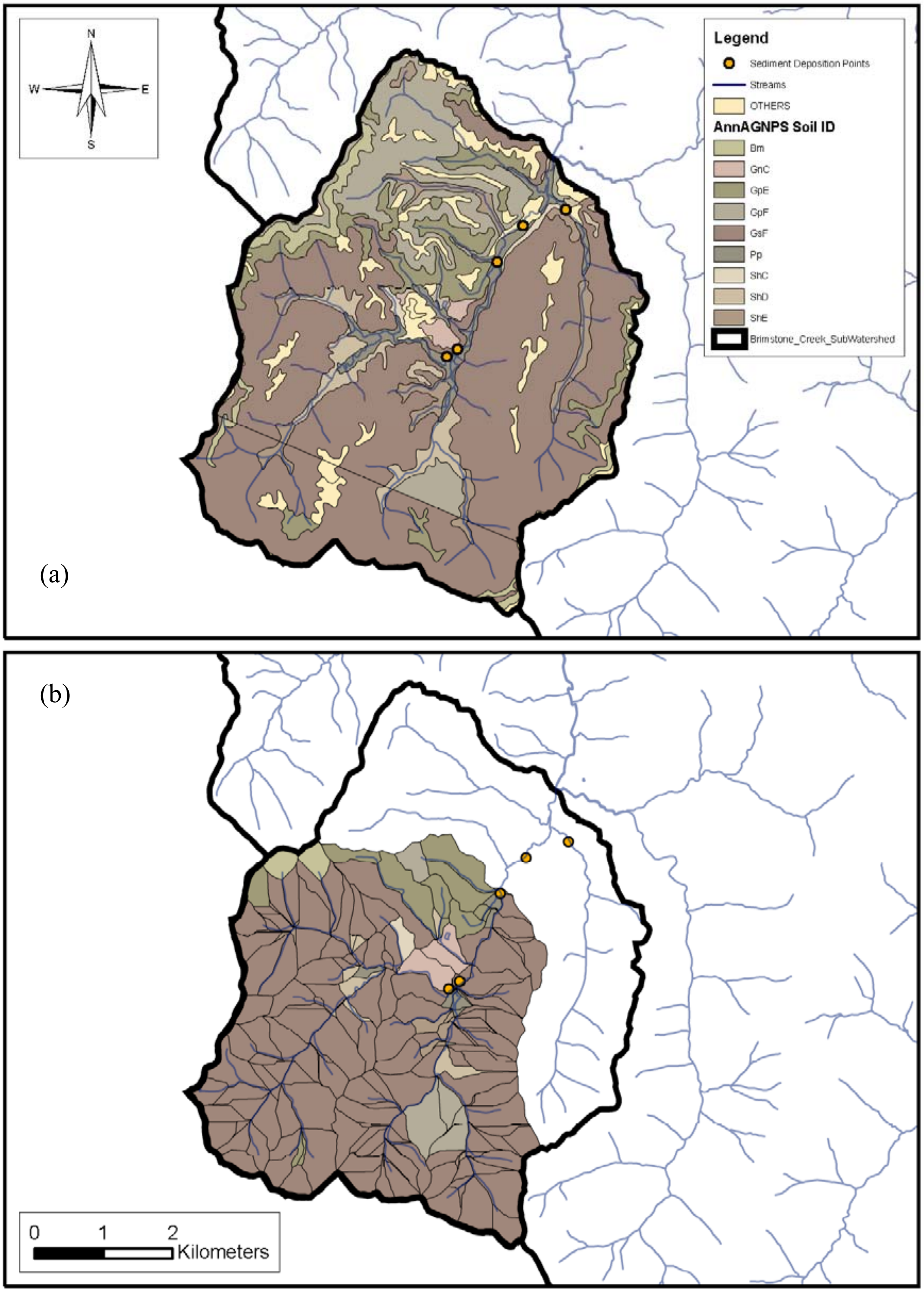


Figure 20: Brimstone Creek AnnAGNPS soil type characterization. (2006)

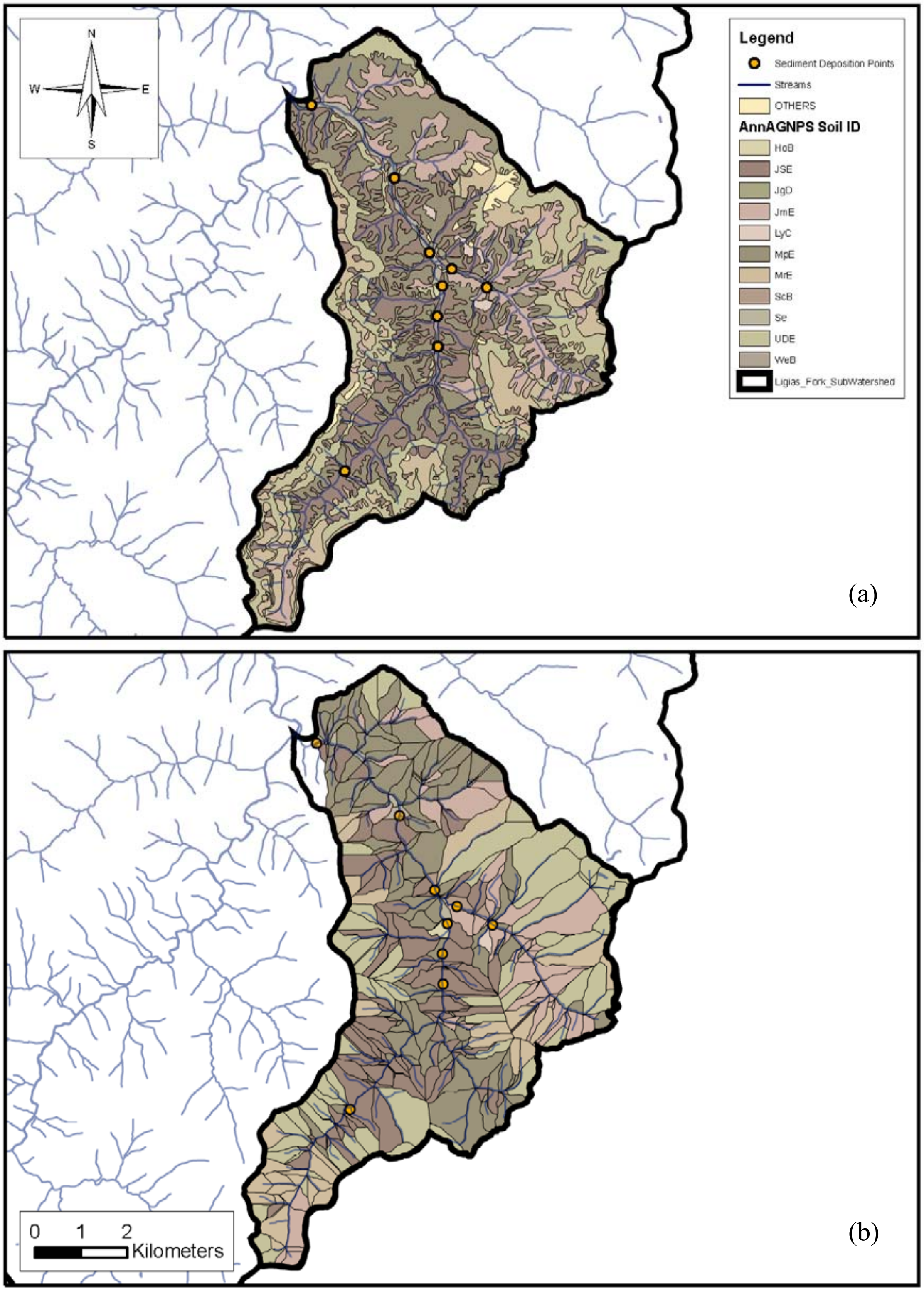


Figure 21: Ligias Fork AnnAGNPS soil type characterization. (2006)

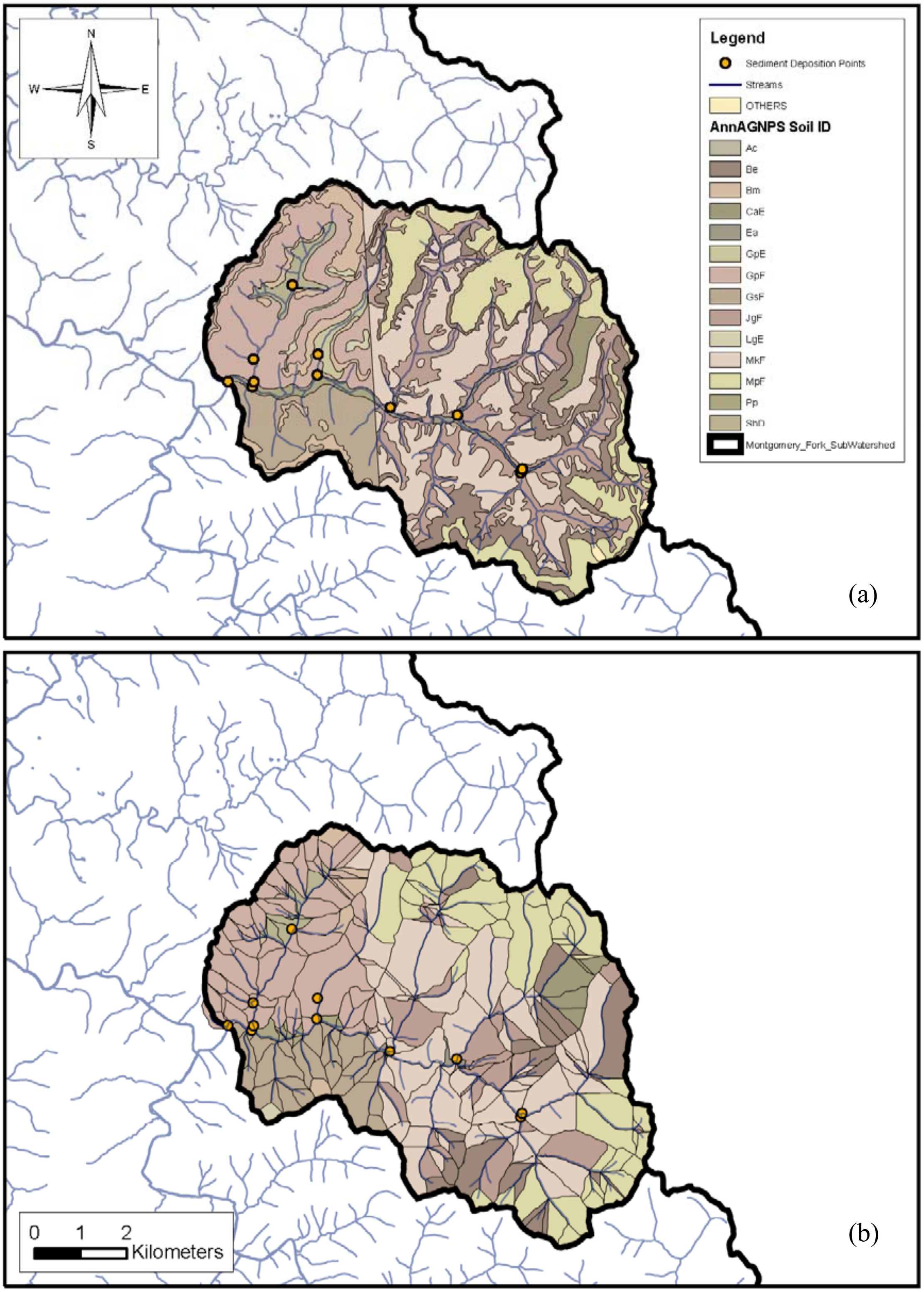


Figure 22: Montgomery Fork AnnAGNPS soil type characterization. (2006)

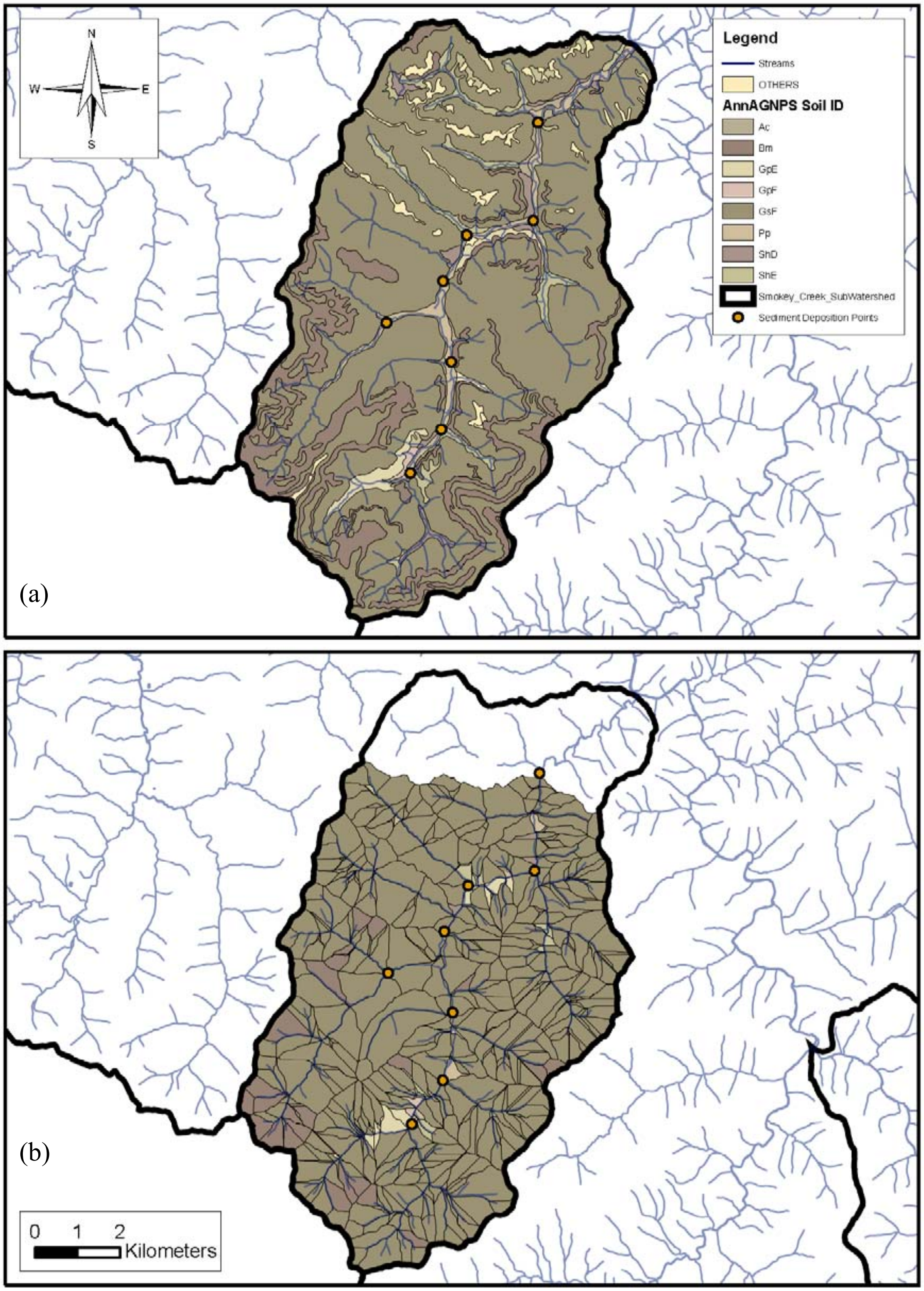


Figure 23: Smokey Creek AnnAGNPS soil type characterization. (2006)

organizing the stage and velocity measurements at the main channel's outlet of each sub-watershed, a stage-discharge relationship could be established to create a series of equations that would transform the continuously collected stage data into a flow rate. The stage-discharge plots for the outlet of each sub-watershed, with the appropriate equations to describe the different relationships, are shown in Figures 24 through 27.

After using the established stage-discharge relationships at the outlet of each sub-watershed, the continuously measured stage data was converted into a flow rate. Between each storm event, which produced a surface runoff amount, the baseflow was separated from the stage data recorded to produce a measured daily runoff amount at each of the four sub-watersheds of interest in the New River Basin. This measured daily surface runoff amount was then compared to the estimated or predicted runoff found from the AnnAGNPS pollutant loading model from a limited amount of local climate data measured from the Big South Fork Weather Station as well as four other local rain gauges near to all sub-watersheds. To better calibrate each sub-watershed, the precipitation data from the Big South Fork River and Recreation Area's Full Weather Station was slightly modified with the precipitation data from the four other tipping bucket rain gauges (which are located around the New River Basin) to better represent the amount of rainfall occurring in this mountainous landscape. The Big South Fork River and Recreation Area's precipitation data was tailored with the other tipping bucket rain gauges based on the tipping bucket's elevation and location in respect to each of the four sub-watersheds used in this study. More tipping bucket rain gauges within each sub-watershed would have been ideal, but due to this study's lack of time, finance, and

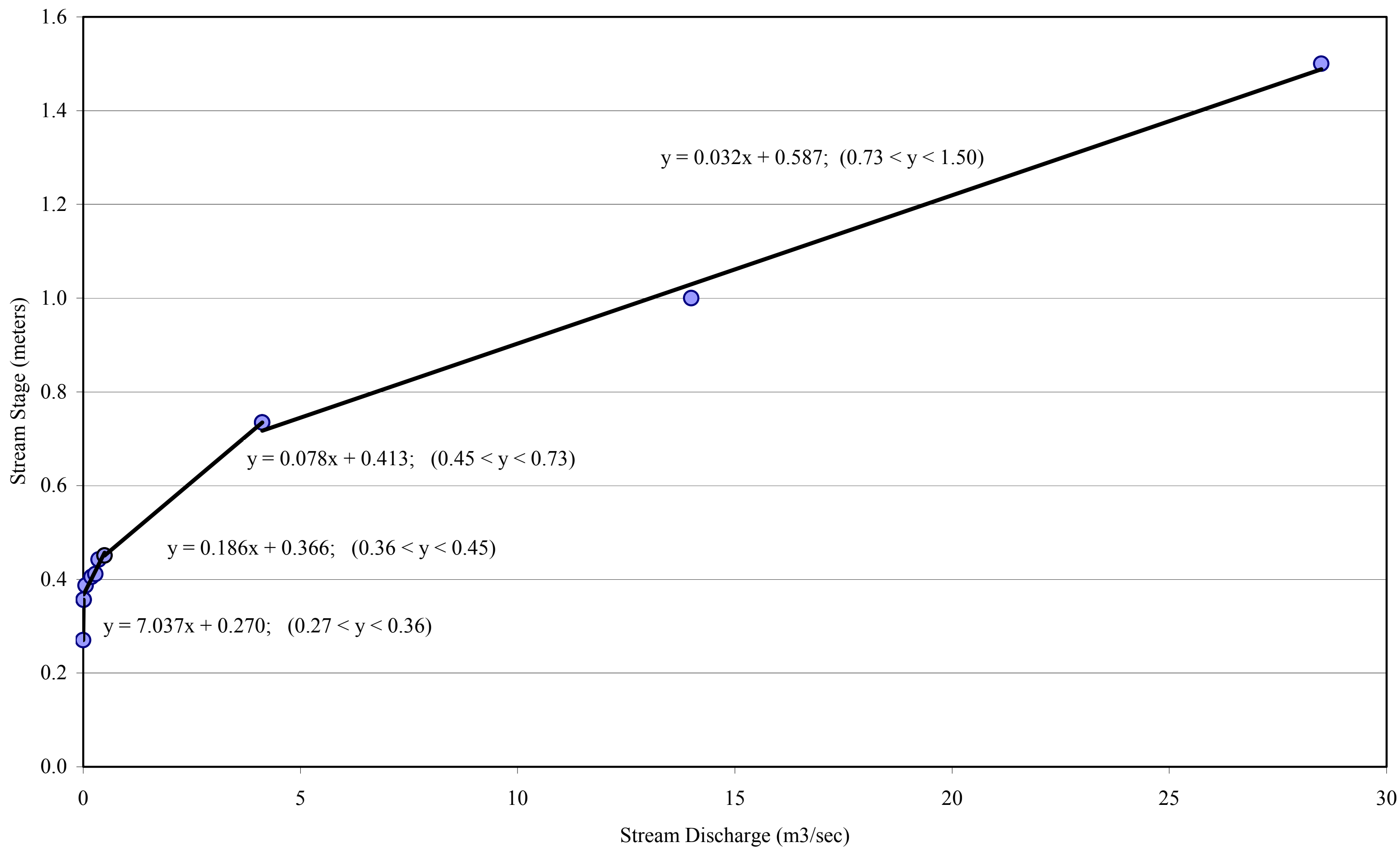


Figure 24: Brimstone Creek stage-discharge relationship.

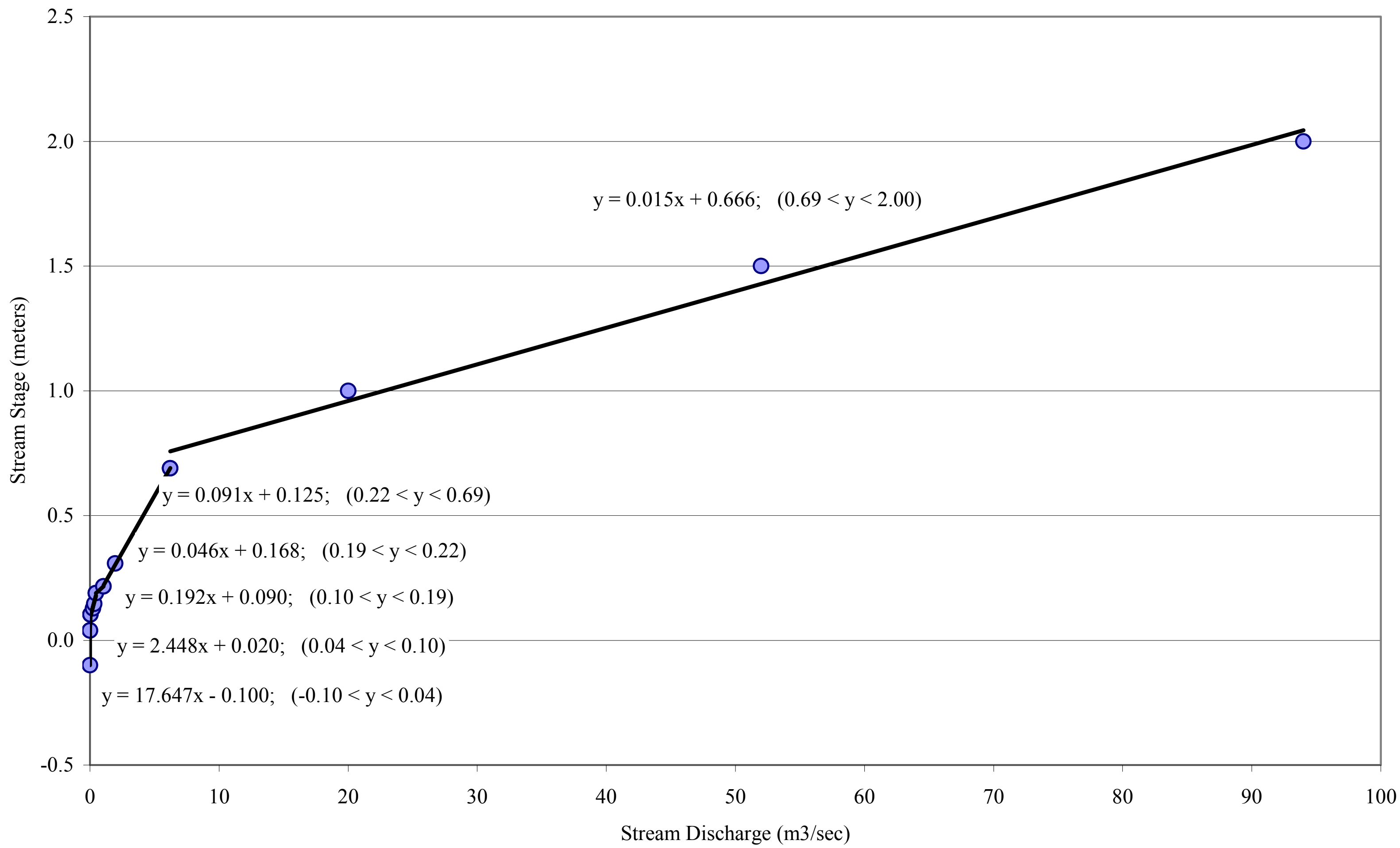


Figure 25: Montgomery Fork stage-discharge relationship.

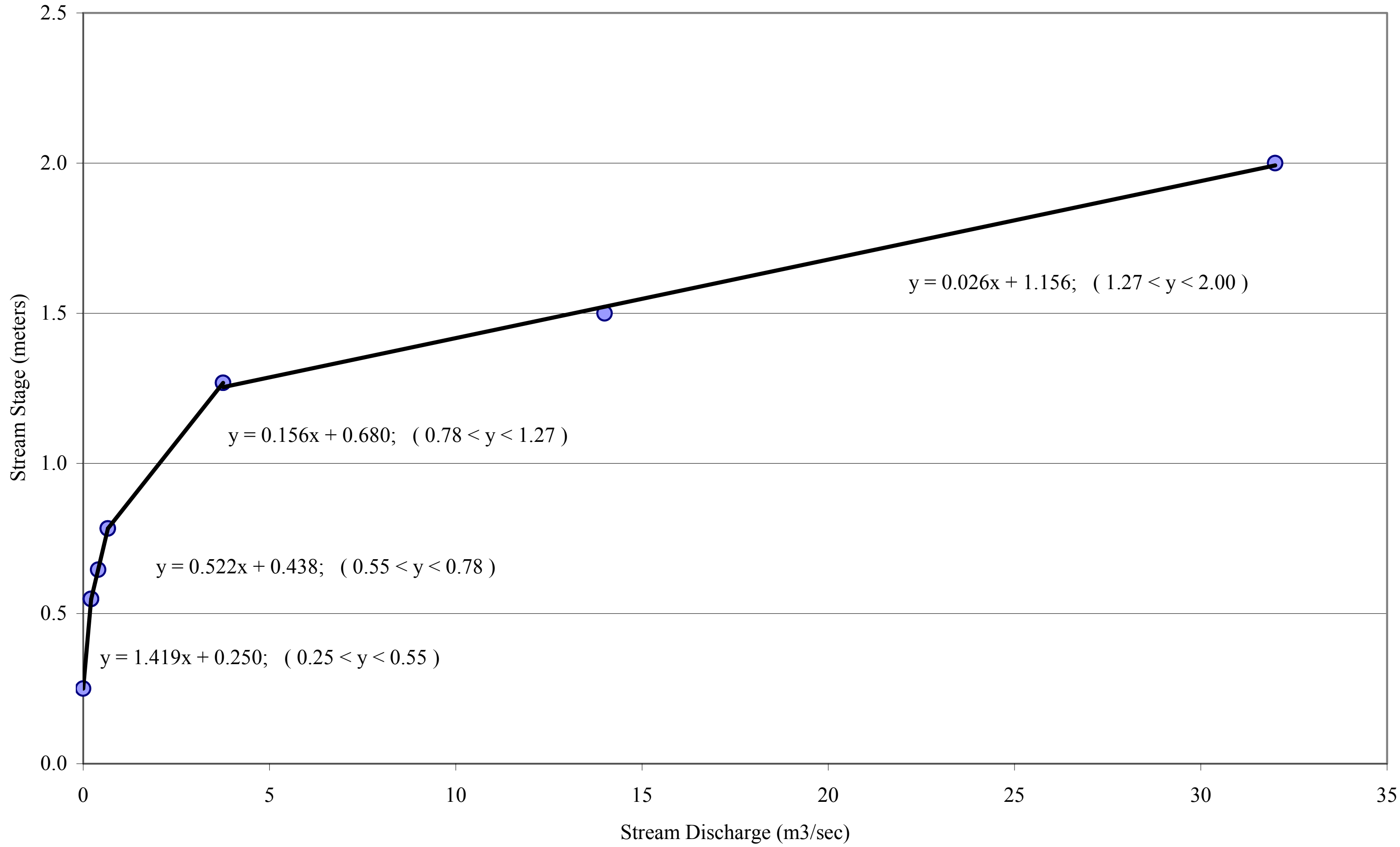


Figure 26: Ligias Fork stage-discharge relationship.

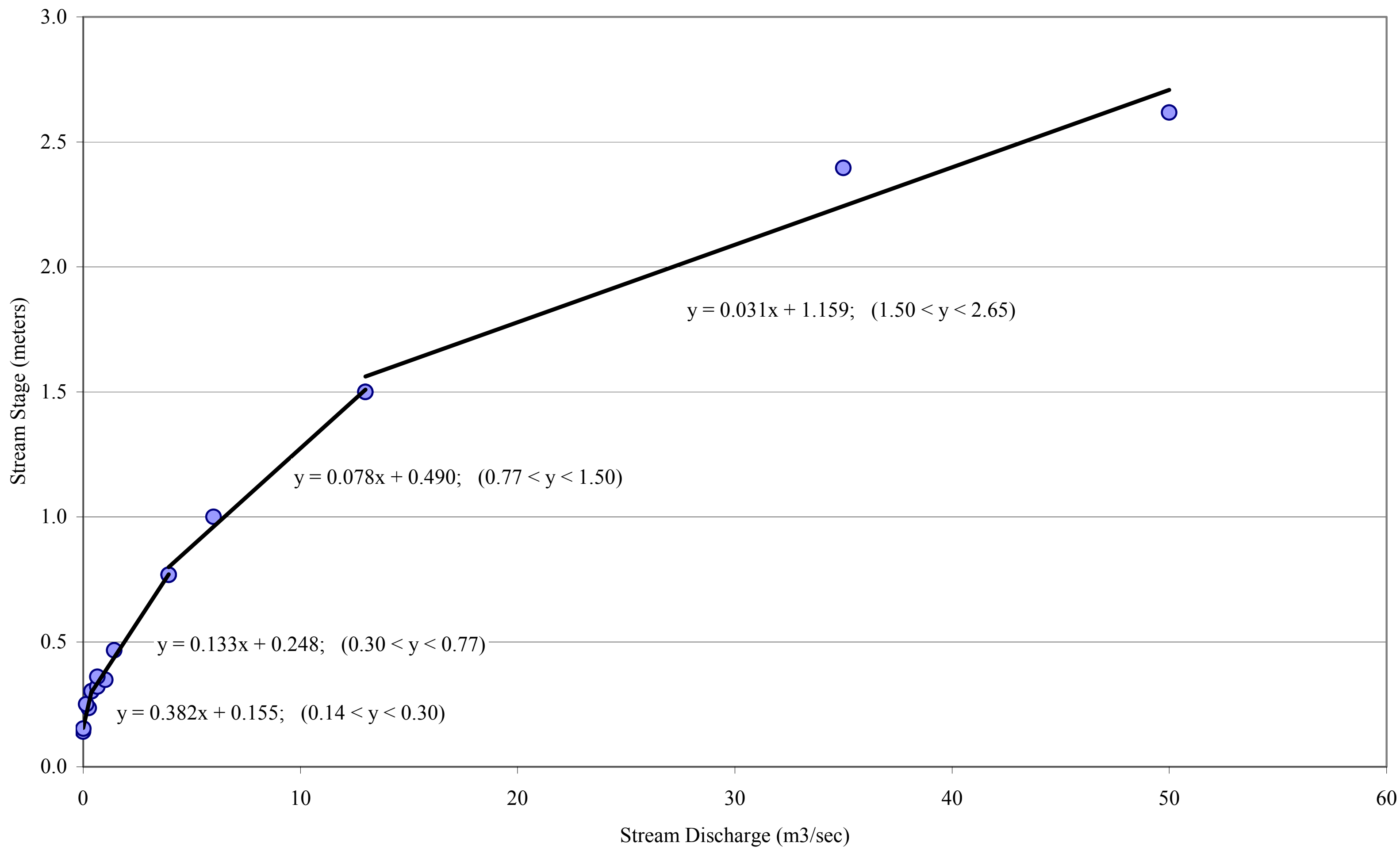


Figure 27: Smokey Creek stage-discharge relationship.

personnel, the only climate data that was used was from devices previously installed by other agencies for long-term measurements.

Since the AnnAGNPS model uses the USDA-NRCS (SCS) Runoff Curve Number (CN) method for different land use activities and hydrologic soil groups, the CNs for in each sub-watershed were slightly modified from standard suggested textbook values to better represent and calibrate the predicted runoff from the AnnAGNPS model with measured values. Table 9 provides the CNs that produced satisfactory results for each of the sub-watershed's common land uses.

The peak flow rate produced by the AnnAGNPS model is a function of the Manning's n roughness coefficients for sheet, shallow, and concentrated flows from the cells and reaches defined in the AnnAGNPS model. Since the Manning's n values for the landscape and streams affects the sediment yield as well, these values for each sub-watershed were adjusted later in the calibration process with that of predicted sediment yield. Overall, the Manning's n values for sheet and concentrated flow are slightly higher than what is suggested from most open channel textbooks for different land use environments. Table 10 summarizes the different Manning's n values used in each sub-watershed with the AnnAGNPS pollutant loading model.

Even with slightly higher Manning's n values for the four different sub-watersheds, the peak flow rate produced from the model was usually overestimated by the AnnAGNPS model in comparison to the measured peak discharge at the outlet of each sub-watershed. The measured peak discharge was obtained from the largest discharge by the stage discharge relationship obtained from the stage recorders. The

Table 9: Runoff curve numbers (CN) used in the AnnAGNPS model

AnnAGNPS Field ID	Land use / Land cover Description	Curve Numbers for Hydrologic Soil Groups			
		A	B	C	D
1	Open Water	0	0	0	0
2	Developed Open Space	47	69	79	86
3	Developed, Low Intensity	51	68	79	84
4	Developed, Medium Intensity	77	85	90	92
5	Developed, High Intensity	81	88	91	93
6	Barren Land (Rock/Sand/Clay)	68	79	86	89
7	Deciduous Forest	36	59	72	79
8	Evergreen Forest	36	59	72	79
9	Mixed Forest	36	59	72	79
10	Shrub/Scrub	34	48	65	73
11	Grassland/Herbaceous	39	61	74	80
12	Pasture/Hay	49	69	79	84
13	Cultivated Crops	66	74	80	82
14	Woody Wetlands	38	62	78	82
101	25% Logged	39	63	75	80
102	50% Logged	45	67	78	82
103	75% Logged	59	77	82	89
104	100% Logged	74	82	88	94
201	Active Surface Mining	77	86	91	94
202	Abandoned Surface Mining	49	66	76	82
301	Dirt Roads	72	82	87	89

Table 10: Manning's n for sheet flow of each cell based on land use

AnnAGNPS Field ID	Land use / Land cover Description	Manning's n Roughness Coefficient		
		Cell Sheetflow	Cell Shallow Concentrated	Reach Concentrated
2	Developed Open Space	0.01	0.025	0.08
3	Developed, Low Intensity	0.01	0.025	0.08
4	Developed, Medium Intensity	0.01	0.025	0.08
5	Developed, High Intensity	0.01	0.025	0.08
6	Barren Land (Rock/Sand/Clay)	0.01	0.025	0.08
7	Deciduous Forest	0.95	0.055	0.08
8	Evergreen Forest	0.95	0.055	0.08
9	Mixed Forest	0.95	0.055	0.08
10	Shrub/Scrub	0.95	0.055	0.08
11	Grassland/Herbaceous	0.15	0.055	0.08
12	Pasture/Hay	0.15	0.025	0.08
13	Cultivated Crops	0.15	0.025	0.08
14	Woody Wetlands	0.50	0.055	0.08
101	25% Logged	0.75	0.025	0.08
102	50% Logged	0.45	0.025	0.08
103	75% Logged	0.15	0.025	0.08
104	100% Logged	0.03	0.025	0.08
201	Active Surface Mining	0.05	0.025	0.08
202	Abandoned Surface Mining	0.05	0.025	0.08
301	Dirt Roads	0.05	0.025	0.08

summarized comparison of the measured versus predicted peak discharge at each sub-watershed can be seen in Figures 28 through 31.

Though the predicted peak discharge from AnnAGNPS was consistently greater than the measured peak discharge at the outlet of the four different sub-watersheds, the predicted total daily runoff matched fairly well with the measured total daily runoff at each sub-watershed. The summarized predicted versus measured total daily runoff at the outlet of each of the sub-watersheds can be seen graphically in Figures 32 through 35. To better represent how well the measured daily runoff agrees with that produced by the AnnAGNPS pollutant loading model, an average runoff discharge frequency plot was developed for each of the four sub-watersheds. Shown in Figures 36 through 39 are the daily average runoff discharge values measured and predicted by the AnnAGNPS pollutant loading model for each of the four sub-watersheds. These values used in the frequency plots have a variety of data points, since some of the sub-watersheds contained measured data beginning in July 2007, and others did not have available measured runoff values until November 2007. As can be seen in the frequency discharge relationships between measured and predicted by AnnAGNPS, the model seems to slightly overestimate smaller runoff causing events, while it slightly underestimates the larger runoff causing events. With most of the sub-watersheds, the medium sized runoff events seem to vary the most from measured versus predicted values with the AnnAGNPS pollutant loading model.

From a uniform set of NRCS TR-55 curve numbers and Manning's n values determined for the different land use characteristics through calibration techniques, the

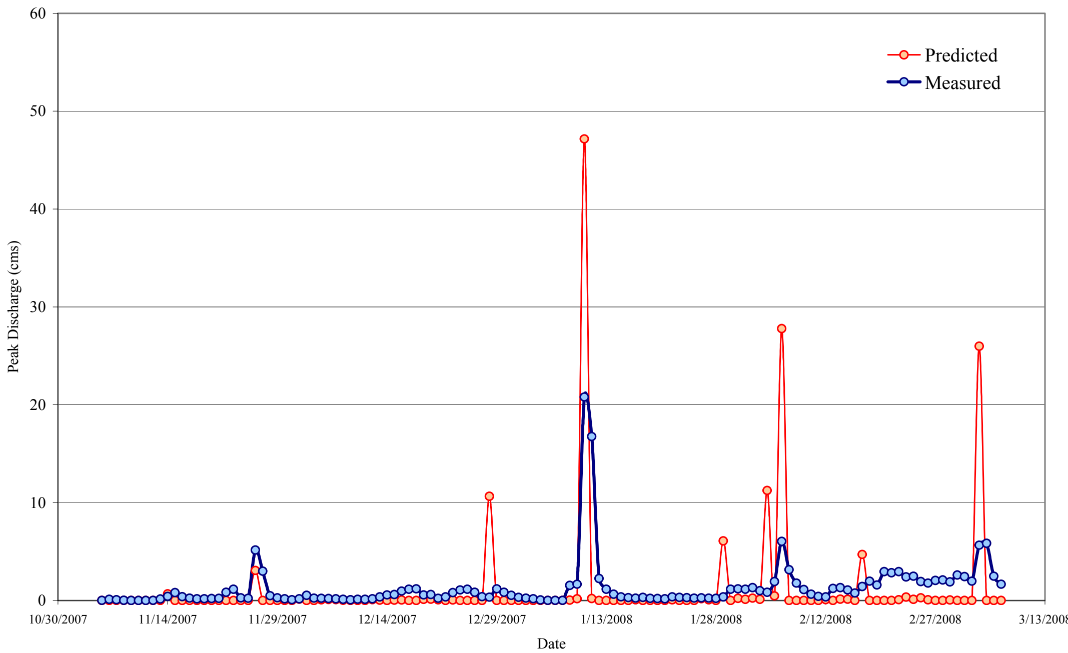


Figure 28: Brimstone Creek modeled peak discharge.

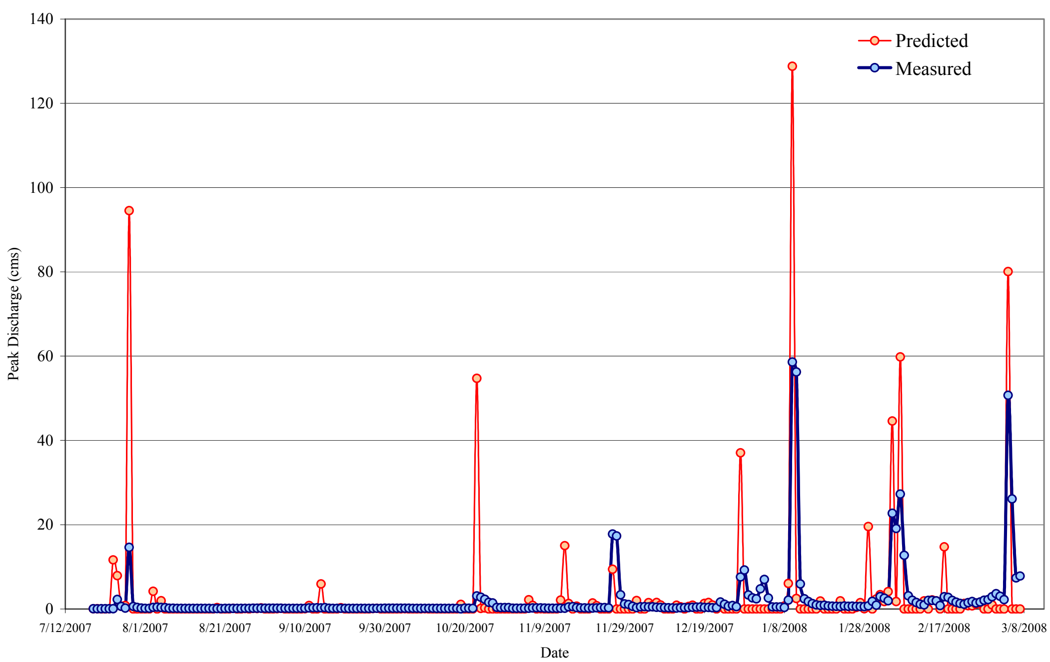


Figure 29: Ligias Fork modeled peak discharge.

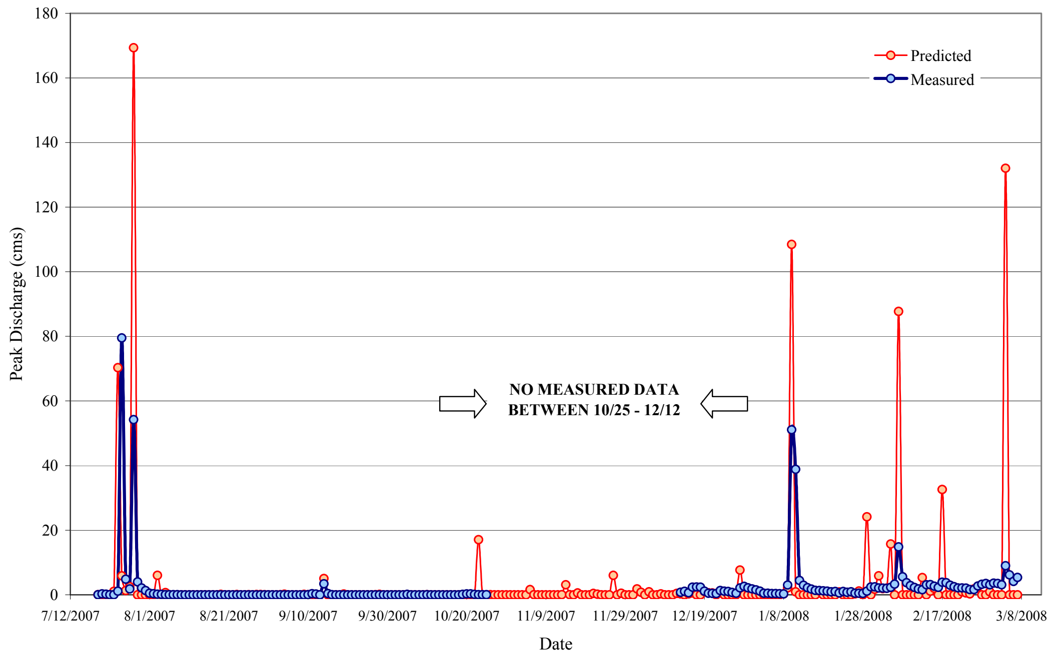


Figure 30: Montgomery Fork modeled peak discharge.

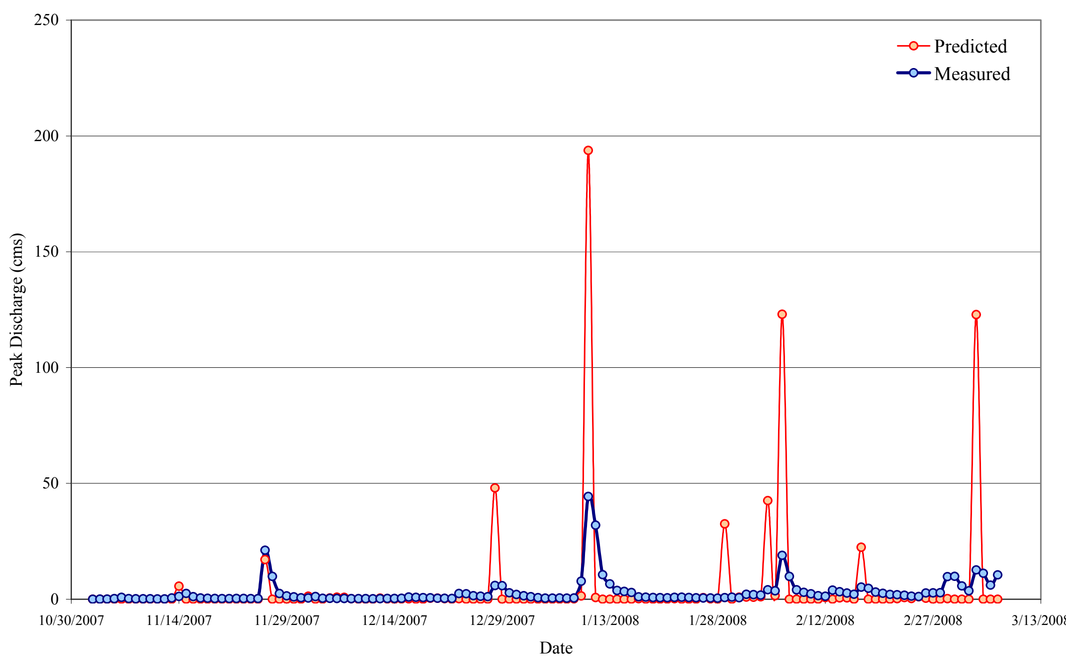


Figure 31: Smokey Creek modeled peak discharge.

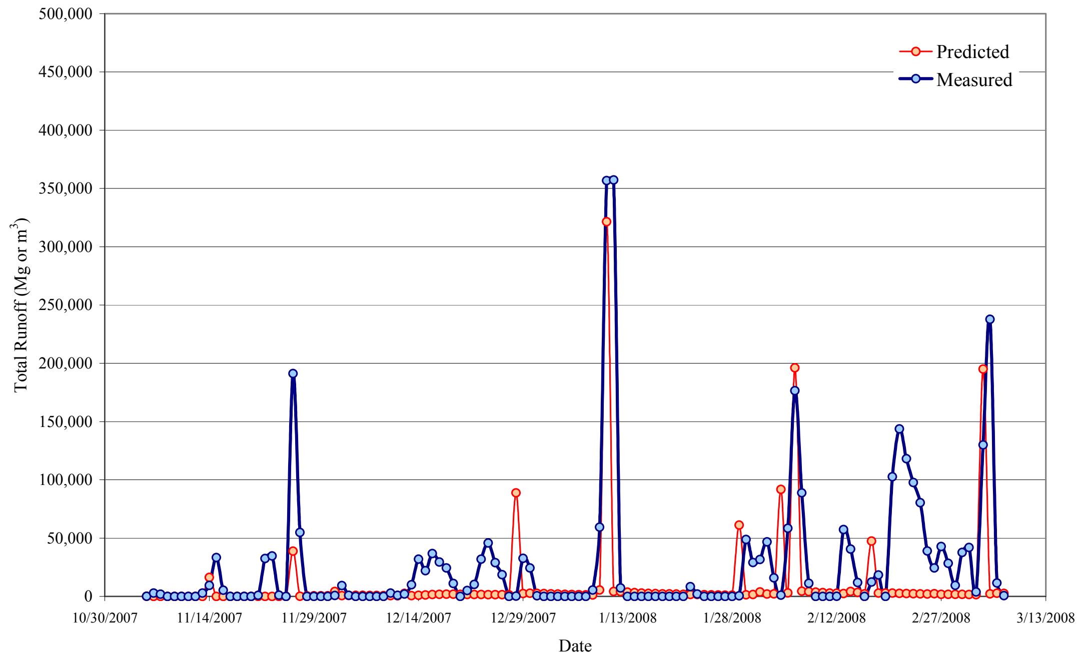


Figure 32: Brimstone Creek modeled total daily runoff.

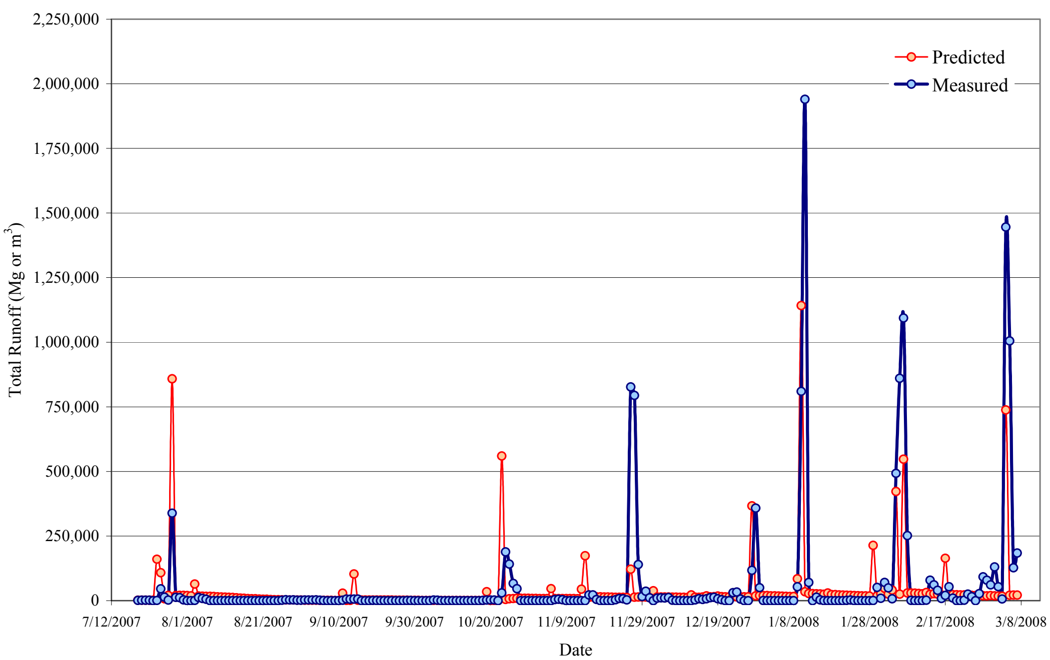


Figure 33: Ligias Fork modeled total daily runoff.

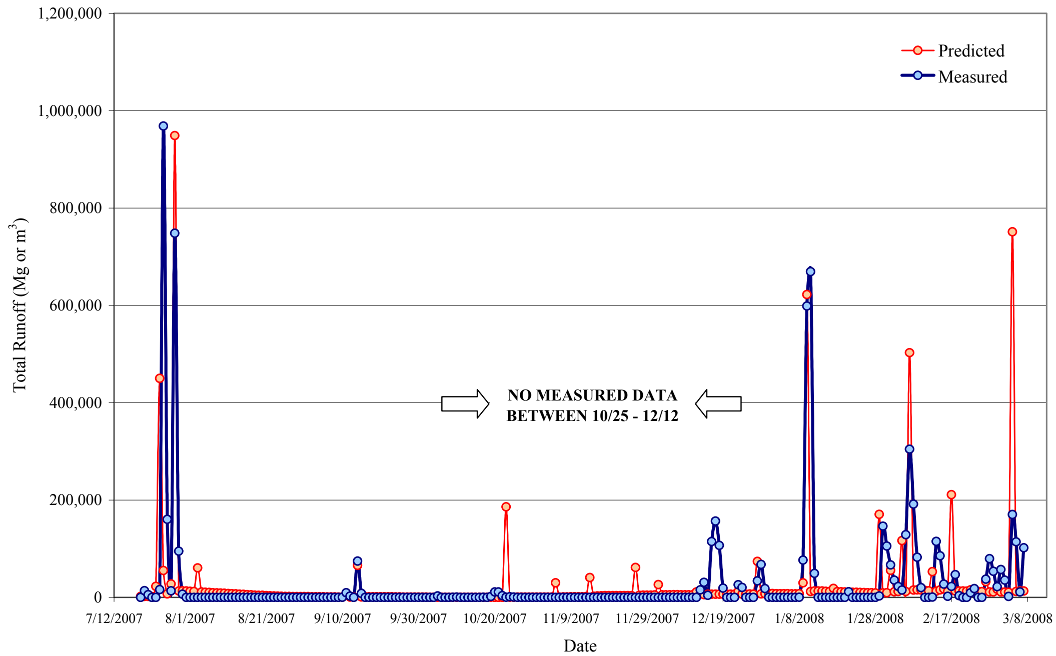


Figure 34: Montgomery Fork modeled total daily runoff.

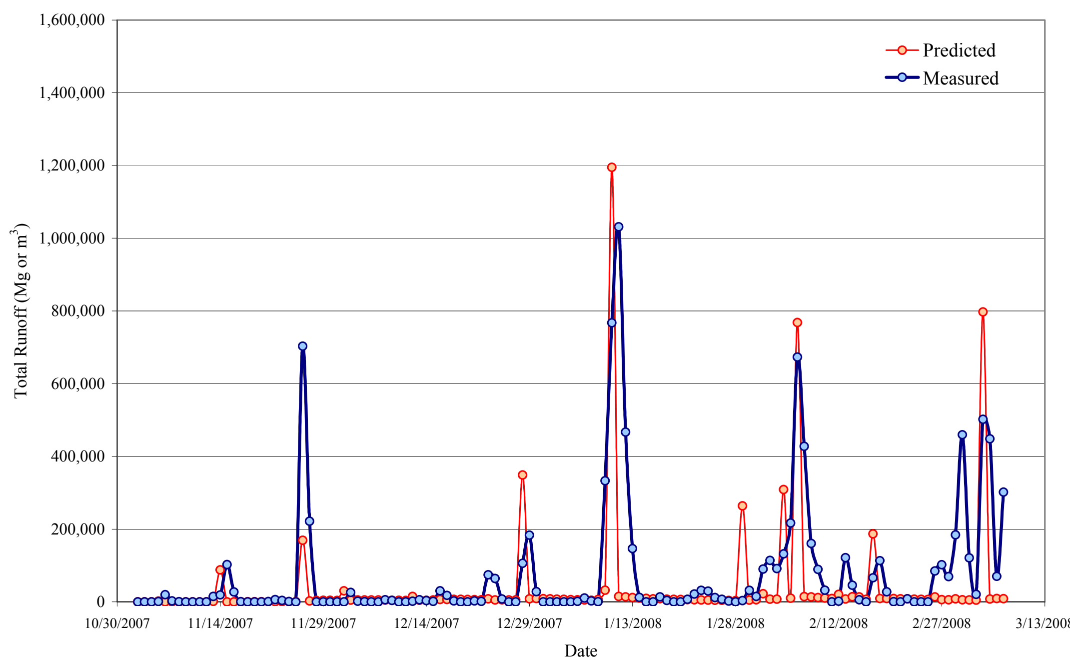


Figure 35: Smokey Creek modeled total daily runoff.

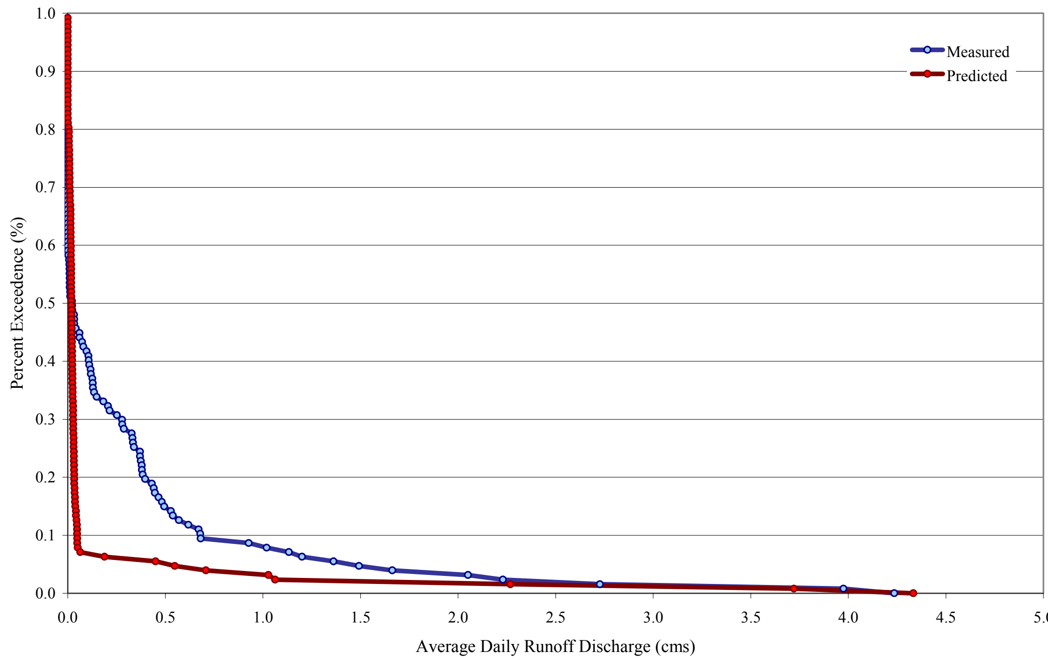


Figure 36: Brimstone Creek discharge frequency curve.

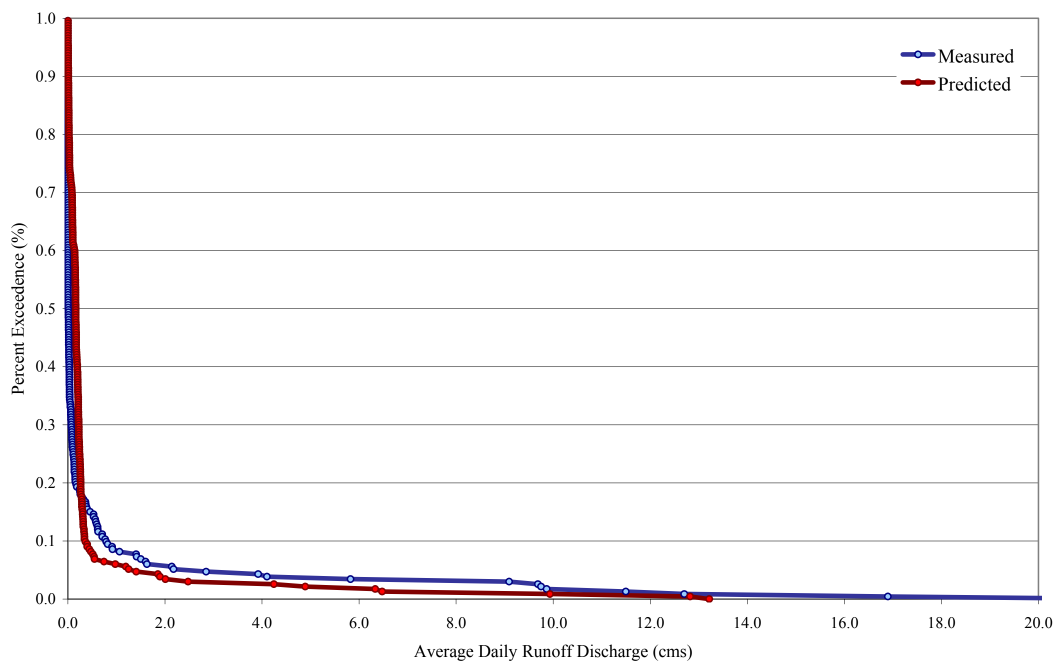


Figure 37: Ligias Fork discharge frequency curve.

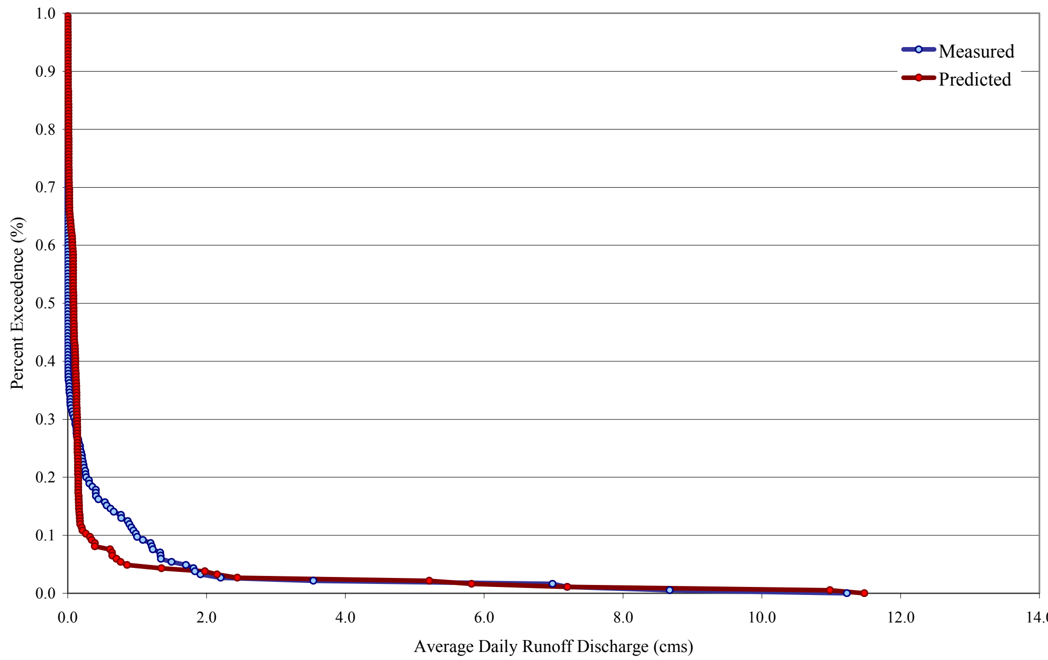


Figure 38: Montgomery Fork discharge frequency curve.

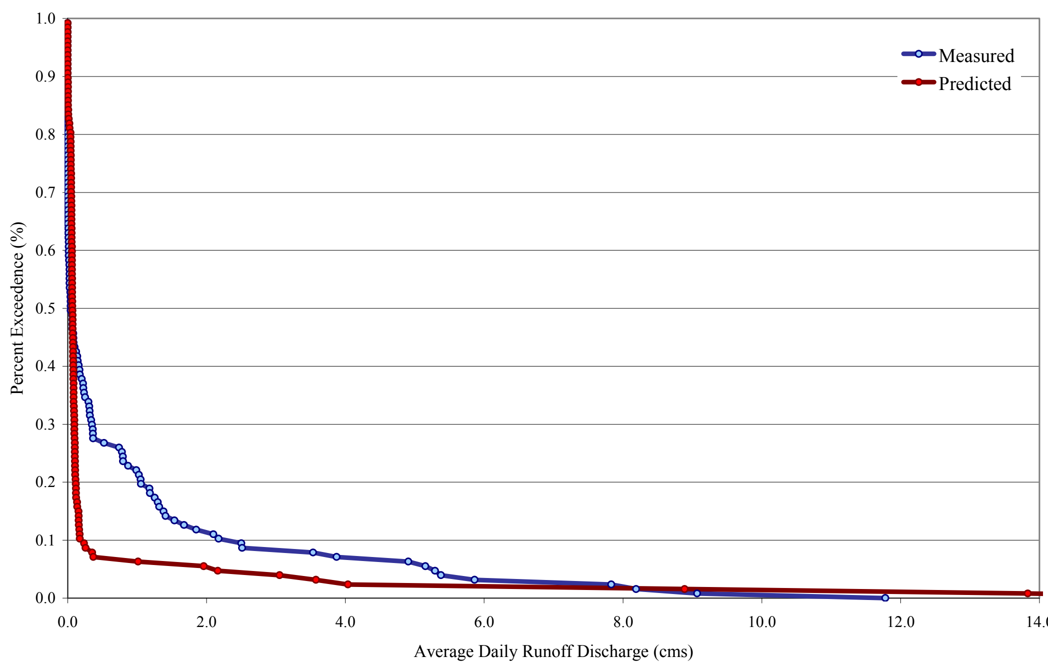


Figure 39: Smokey Creek discharge frequency curve.

predicted daily runoff values estimated by the AnnAGNPS model seem to correspond to the actual New River hydrology as well as possible with the limited amount of weather data, time, and personnel for this project. Overall, there is some error in the model's computations of peak flow which are likely due to the steep slope of the New River Basin topography, insufficient weather data, and the NRCS TR-55's assumption of all storm event intensities having a Type II distribution. The daily total surface runoff amount also contains some error which is largely due to inadequate weather data available and the daily time step of the AnnAGNPS model which does not carry a continuous storm event over into the next day.

4.3.3 Sediment Yield Calibration

After the AnnAGNPS pollutant loading model produced satisfactory storm water runoff results with the limited amount of time and weather data available for all four sub-watersheds in the New River Basin, the calibration of the sediment yield was initiated. The AnnAGNPS pollutant loading model uses the RUSLE variables to estimate the daily sediment yield of a drainage area. The RUSLE C and P factors are defined by the user for different land use activities in a designated area. To properly calibrate each sub-watershed's sediment yield through the RUSLE C and P factors, a set of TSS samples was obtained at the outlet of each sub-watershed for a variety of different storm events.

Using the data collected from the TSS samples, the majority of the AnnAGNPS pollutant loading model could be calibrated to match current sediment yields occurring on each sub-watersheds' landscape. The AnnAGNPS model uses flow cells to group large areas with homogeneous land use and soil data to make computations easier and quicker. By grouping a dominant land use and soil type for a large area for erosion and sediment yield computations, many of the smaller, yet larger sediment-contributing sources, like dirt roads, will likely not be detected.

From several visits throughout the New River area, the dirt roads were a significant source of sedimentation into the streams (as shown in Figure 40). The dirt roads in the region were usually associated with surface mining activities, forest logging, or various alternative terrain vehicle (ATV) trails. From field observations, the dirt roads used for travel to logged areas, mined areas, and other locations often contained drainage ditches and culverts that created gullies down to the local streams. By taking flow measurements and grab samples from different dirt road gullies during several storm events, the sediment yield from dirt roads was analyzed through the TSS analysis. By summarizing the daily flow rate within a road drainage way, its TSS concentration, and the amount of runoff contributing from this roadway, a relationship could be derived

Figure 40: Sediment yield from dirt road at Montgomery Fork

to represent the amount of sediment yield (Qs) for an estimated storm water runoff (Qw) amount.

The AnnAGNPS model uses an exponential relationship between Qs and Qw to provide an amount of sediment being contributed from a flow cell in addition to the amount generated from the defined dominant land use and soil type. From a small set of different grab samples from dirt roads from different sub-watersheds, the following equation (Equation 11) was derived to represent all the dirt roads in each sub-watershed of the New River area with the classical gully command in the AnnAGNPS pollutant loading model. Note that the exponential relationship for the sediment yield produced as a function of from dirt roads was estimated on only seven sets of grab samples for a variety of soil and limestone gravel based roads with different degrees of usage. Therefore, this set of data is very approximate and just provides a general means of accounting for the un-paved road systems within the sediment budget of the New River sub-watersheds. The graphical representation of the exponential dirt road equation developed can be found as Figure 41.

$$Qs = 0.01Qw^{0.67} \tag{11}$$

From the relationship established with the amount of runoff from a dirt road area and the amount of sediment yield produced, the AnnAGNPS classical gully command was used to identify each cell in each sub-watershed that had a large road drainage area. Since some of the flow cells only contained a few small pieces of dirt roads, the flow

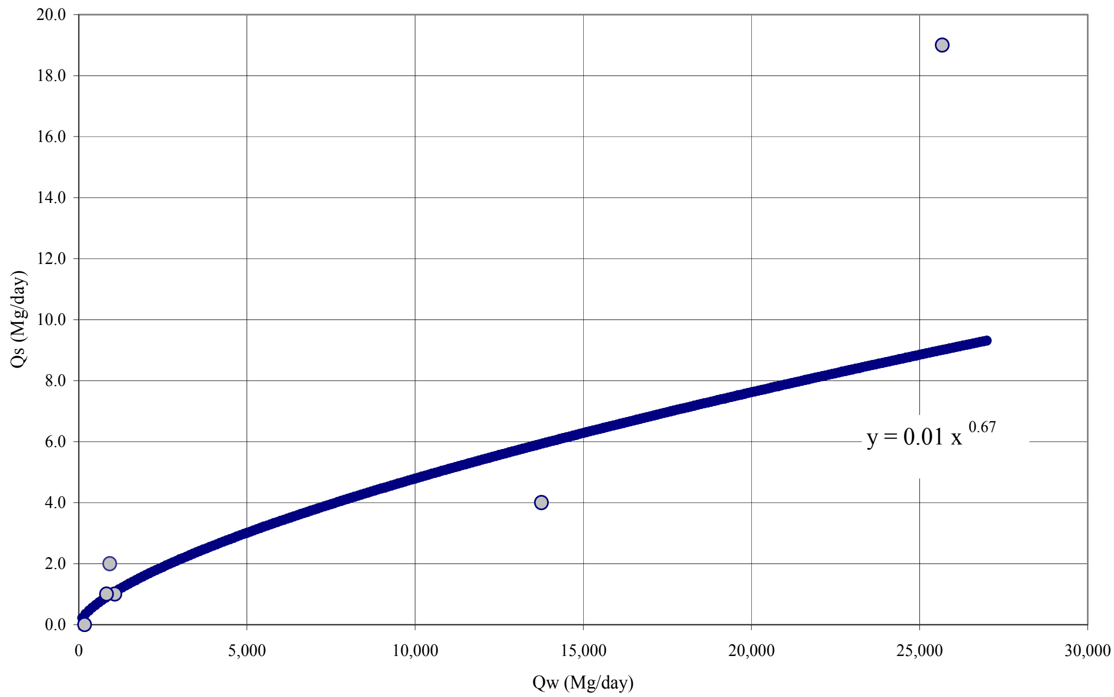


Figure 41: Sediment yield for dirt roads in the New River Basin. (2007)

cells that had a dirt road network of 5% of the cell's total area, or 0.5 hectares of area, were selected for the classical gully command. A summary of the number of flow cells that were identified to have dirt roads in each sub-watershed for the AnnAGNPS model can be seen in Table 11.

After the dirt roads within each sub-watershed were implemented into the AnnAGNPS pollutant loading model, the next objective was to calibrate the RUSLE C and P factors for the different land uses found. From a series of trial and error analyses in the range of common text book values and previous AnnAGNPS modeling studies, the RUSLE C and P factors were adjusted for a variety of different land use features until a satisfactory sediment yield was produced to provide a similar value to that measured in

Table 11: Summary of AnnAGNPS flow cells with dirt roads

Watershed	Number of Cells with Dirt Roads (---)	Total Cell Area with Dirt Roads (ha)	Total Watershed Area (ha)	Percent of Watershed with Dirt Roads (%)
Brimstone Creek	16	4.56	2,181	0.21%
Ligias Fork	56	63.81	5,218	1.22%
Montgomery Fork	57	42.68	5,748	0.74%
Smokey Creek	77	68.94	7,300	0.94%

the field. A summary of the RUSLE C and P factors used for a variety of different land use applications for each sub-watershed can be seen in Tables 12 and 13.

Once several suspended sediment samples were captured in the outlet of each sub-watershed, the TSS value for a given time and day were multiplied by the total measured runoff to estimate a suspended solids content that would be comparable to the AnnAGNPS's daily sediment yield value. To check the acceptability of TSS measurements found for this study, in each of the four sub-watersheds, the suspended sediment samples taken by the USGS in the New River Basin area were used to compare with the samples collected by The University of Tennessee, Knoxville. From Table 14, the TSS results taken by the USGS at two different gauging stations located on the New River stream for 2006 through 2008 contain similar concentrations to the TSS measurements taken at the four sub-watersheds used in this study. Table 14 is presented to show that the TSS concentrations determined for this study are in agreement with typical suspended sediment concentrations currently found by others in the New River Basin. The suspended sediment data collected by the USGS for the two different gauging

Table 12: Non-crop data values used to estimate the C-Factor.

Non-Crop ID	Non-Crop Description	Annual Root Mass (kg/ha)	Annual Cover Ratio (0-1)	Annual Rain Fall Height (m)	Surface Residue Cover (%)
2	Developed Open Space	0	1.00	0.00	0
3	Developed, Low Intensity	3000	0.80	0.03	40
4	Developed, Medium Intensity	2000	0.90	0.03	40
5	Developed, High Intensity	1000	0.90	0.03	40
6	Barren Land (Rock/Sand/Clay)	0	0.00	0.00	0
7	Deciduous Forest	7000	0.95	4.57	85
8	Evergreen Forest	6500	0.95	4.57	80
9	Mixed Forest	6750	0.95	4.57	80
10	Shrub/Scrub	6500	0.95	1.22	60
11	Grassland/Herbaceous	3000	0.90	0.03	80
12	Pasture/Hay	3500	0.95	0.03	80
13	Cultivated Crops	4000	0.80	0.03	50
14	Woody Wetlands	6500	0.95	4.57	80
101	25% Logged	1700	0.70	4.57	45
102	50% Logged	1200	0.45	4.57	40
103	75% Logged	800	0.30	4.57	20
104	100% Logged	350	0.05	4.57	10
201	Active Surface Mining	250	0.20	0.03	5
202	Abandoned Surface Mining	900	0.25	1.00	15
301	Dirt Roads	0	0.00	0.00	0

Table 13: Management Field data values used.

Management Field ID	Land use Description	Field Land use Type	Percent Rock Cover (%)	RUSLE Sub P-Factor (0-1)	Interrill Erosion Code (1-4)
2	Developed Open Space	URBAN	0	1	2
3	Developed, Low Intensity	URBAN	30	1	3
4	Developed, Medium Intensity	URBAN	55	1	3
5	Developed, High Intensity	URBAN	80	1	3
6	Barren Land (Rock/Sand/Clay)	URBAN	50	1	2
7	Deciduous Forest	FOREST	25	1	4
8	Evergreen Forest	FOREST	25	1	4
9	Mixed Forest	FOREST	25	1	4
10	Shrub/Scrub	FOREST	25	1	4
11	Grassland/Herbaceous	PASTURE	20	1	3
12	Pasture/Hay	PASTURE	20	1	3
13	Cultivated Crops	PASTURE	15	1	2
14	Woody Wetlands	FOREST	25	1	4
101	25% Logged	FOREST	25	1	4
102	50% Logged	FOREST	25	1	4
103	75% Logged	FOREST	25	1	4
104	100% Logged	FOREST	25	1	4
201	Active Surface Mining	URBAN	85	1	4
202	Abandoned Surface Mining	URBAN	50	1	4
301	Dirt Roads	URBAN	80	1	4

Table 14: Comparison of USGS TSS samples near study sites.

Agency	Sample Site	Number of Samples Taken	Sample Period	Average TSS (mg/L)	Minimum TSS (mg/L)	Maximum TSS (mg/L)
USGS	New River at New River USGS Gauging Station	22	2006-2008	128	1	434
USGS	New River at Cordell Bridge USGS Gauging Station	22	2006-2008	197	1	624
UT	Brimstone Creek	9	2008	38	6	87
UT	Ligias Fork	9	2008	159	17	454
UT	Montgomery Fork	8	2008	143	9	564
UT	Smokey Creek	8	2008	120	1	571

USGS: TSS samples taken independent of this study by U.S. Geological Survey on the New River
UT: TSS samples taken for this study by The University of Tennessee

stations located on the New River was provided to the OSM on February 28, 2008 from the Tennessee Water Science Center at the Knoxville, TN Field Office.

Tables 15 through 18 summarize the TSS analysis as well as the multiple measured versus predicted suspended solids concentration by the AnnAGNPS pollutant loading model after being calibrated. As can be seen from many of the discrepancies between the measured and predicted suspended solids contents, it should be noted that many of the measured TSS samples were not collected during peak flow and peak suspended sediment conditions in most the streams, so it is assumed that some of the measured suspended solids concentrations are considerably lower than that of actual concentrations. It is also interesting to note that a storm that enters into a watershed from the late evening hours to the early morning hours of the next day creates some complications with the AnnAGNPS model. Looking at January 10 and 11, the measured suspended sediment concentrations summarized together are close to the value predicted

Table 15: Brimstone Creek suspended sediment summary.

Watershed:	Brimstone Creek @ BSC-1			Drainage Area (m^2):		21,810,000	
Sample No. (---)	Sample Date (mm/dd/yyyy)	Measured Suspended Solids (mg/L)	Flow Rate during Sampling (m^3/sec)	Measured Peak Flow (m^3/sec)	Measured Total Runoff (m^3)	Measured Suspended Solids (Mg/day)	Predicted Suspended Solids (Mg/day)
1	1/10/2008	78.40	1.00	11.74	360,000	28.2	38.0
2	1/11/2008	55.25	4.50	9.84	360,000	19.9	0.3
3	1/26/2008	0.00	0.27	0.27	0	0.0	0.0
4	1/29/2008	3.50	0.25	0.29	600	0.0	0.2
5	1/30/2008	5.90	0.45	0.59	50,000	0.3	0.0
6	2/1/2008	8.67	0.31	0.59	32,000	0.3	0.0
7	2/6/2008	87.33	4.54	4.77	180,000	15.7	23.6
8	2/12/2008	8.00	0.33	0.36	100	0.0	0.9
9	2/13/2008	6.00	1.07	1.23	41,000	0.2	0.0
10	2/21/2008	8.00	2.76	2.83	144,000	1.2	0.0
11	2/22/2008	11.00	2.72	2.95	118,000	1.3	0.0
12	3/4/2008	78.00	2.91	5.65	130,000	10.1	104.8

Table 16: Ligias Fork suspended sediment summary.

Watershed:	Ligias Fork @ LF-1			Drainage Area (m^2):		52,194,800	
Sample No. (---)	Sample Date (mm/dd/yyyy)	Measured Suspended Solids (mg/L)	Flow Rate during Sampling (m^3/sec)	Measured Peak Flow (m^3/sec)	Measured Total Runoff (m^3)	Measured Suspended Solids (Mg/day)	Predicted Suspended Solids (Mg/day)
1	1/10/2008	58.05	1.40	4.49	660,000	38.3	149.1
2	1/11/2008	32.25	1.63	4.38	1,550,000	50.0	1.2
3	1/30/2008	17.40	1.22	1.51	50,000	0.9	0.0
4	2/1/2008	252.00	1.75	1.82	70,000	17.6	3.4
5	2/6/2008	342.00	3.05	3.08	1,090,000	372.8	57.3
6	2/12/2008	28.00	0.88	0.96	1,400	0.0	1.7
7	2/13/2008	454.00	1.01	2.05	79,000	35.9	0.0
8	2/21/2008	16.00	1.17	1.31	0	0.0	0.0
9	2/22/2008	18.00	1.03	1.11	1,700	0.0	0.6
10	3/4/2008	230.00	12.75	50.73	1,450,000	333.5	159.9

Table 17: Montgomery Fork suspended sediment summary.

Watershed:	Montgomery Fork @ MFCS-1			Drainage Area (m^2):		57,483,900	
Sample No. (---)	Sample Date (mm/dd/yyyy)	Measured Suspended Solids (mg/L)	Flow Rate during Sampling (m^3/sec)	Measured Peak Flow (m^3/sec)	Measured Total Runoff (m^3)	Measured Suspended Solids (Mg/day)	Predicted Suspended Solids (Mg/day)
1	1/10/2008	162.90	2.08	13.92	600,000	97.7	138.2
2	1/11/2008	34.50	5.98	12.01	670,000	23.1	0.0
3	1/26/2008	1.00	0.85	0.85	0	0.0	0.0
4	1/30/2008	9.07	2.34	2.54	150,000	1.4	0.0
5	2/1/2008	114.80	1.24	2.21	70,000	8.0	15.9
6	2/6/2008	564.00	7.37	8.25	310,000	174.8	113.8
7	2/12/2008	10.00	1.47	1.57	700	0.0	12.9
8	2/13/2008	66.00	2.20	3.11	115,000	7.6	0.0
9	2/21/2008	26.00	1.98	2.14	0	0.0	0.0
10	2/22/2008	49.00	1.77	2.14	10,000	0.5	1.2
11	3/4/2008	142.00	3.11	9.00	170,000	24.1	293.9

Table 18: Smokey Creek suspended sediment summary.

Watershed:	Smokey Creek @ SC-1			Drainage Area (m^2):		73,015,200	
Sample No. (---)	Sample Date (mm/dd/yyyy)	Measured Suspended Solids (mg/L)	Flow Rate during Sampling (m^3/sec)	Measured Peak Flow (m^3/sec)	Measured Total Runoff (m^3)	Measured Suspended Solids (Mg/day)	Predicted Suspended Solids (Mg/day)
1	1/10/2008	150.30	3.95	16.55	800,000	120.2	689.2
2	1/11/2008	134.25	8.96	13.82	1,000,000	134.2	2.4
3	1/26/2008	1.00	0.59	0.62	7,000	0.0	0.0
4	1/30/2008	32.00	0.82	0.97	30,000	1.0	0.0
5	2/1/2008	117.60	1.73	2.14	90,000	10.6	13.9
6	2/6/2008	570.67	10.55	10.95	675,000	385.2	418.0
7	2/12/2008	28.00	1.14	1.28	1,600	0.0	12.9
8	2/13/2008	19.00	3.91	3.91	120,000	2.3	0.0
9	2/21/2008	6.00	1.85	2.08	0	0.0	0.0
10	2/22/2008	8.00	1.71	1.96	9,000	0.1	3.0
11	3/4/2008	143.00	11.26	12.63	500,000	71.5	852.3

by AnnAGNPS on just the 10^{th} of January, since that is the day when the largest portion of the storm entered into the sub-watersheds. The model did not know that this January 10^{th} storm passed through during the late evening hours and carried over to the early morning hours of the next day; it just knew that on January 10, there was some amount of precipitation that followed a Type II distribution. Therefore, the model not appropriately reacting to an over-night storm is due to the model's daily time step computations as well as the same precipitation distribution type (from the NRCS TR-55 runoff computations) based on the location of the study.

To visually understand the measured versus predicted suspended sediment values for each sub-watershed, see Figures 42 through 45. It must be noted that only a few suspended sediment samples were measured in the time interval shown on the figures. Therefore, the measured suspended sediment values are not continuous in time, so there are several increases in suspended sediment shown by AnnAGNPS that were not measured in the field. To help provide insight on when the measured suspended sediment samples were taken, a numerical concentration value is shown above the measured bars.

From using the outlet of each sub-watershed to calibrate the actual to predicted runoff and sediment yield values naturally occurring, each RGA point where fine bed sediment deposits were collected in the streams would be set as a different watershed outlet to provide an annual average sediment yield value in terms of clays, silts, and sands. For each sample site where suspended sediment was collected, the AnnAGNPS program would only consider the area and its contents of each sub-watershed draining into that point of interest. Since the fine stream bed sediment deposits were collected

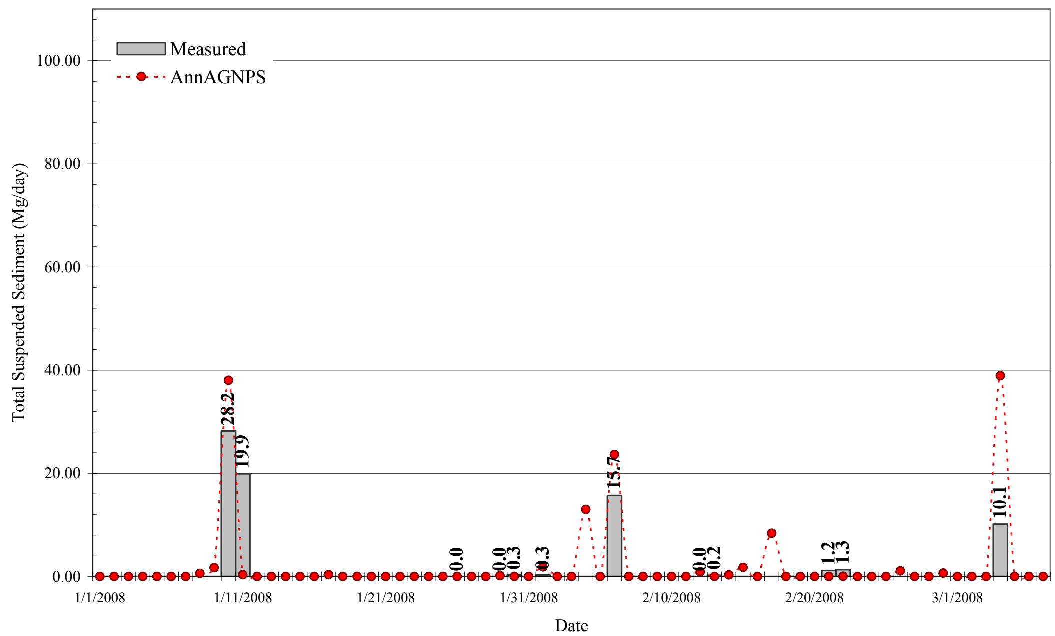


Figure 42: Brimstone Creek measured and predicted suspended sediment.

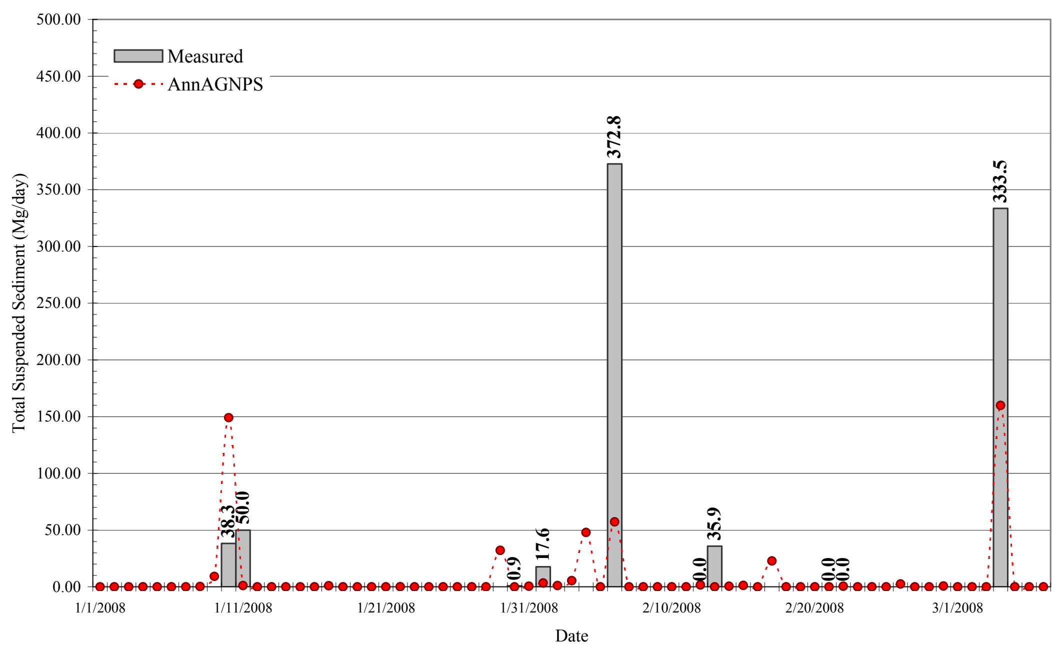


Figure 43: Ligias Fork measured and predicted suspended sediment.

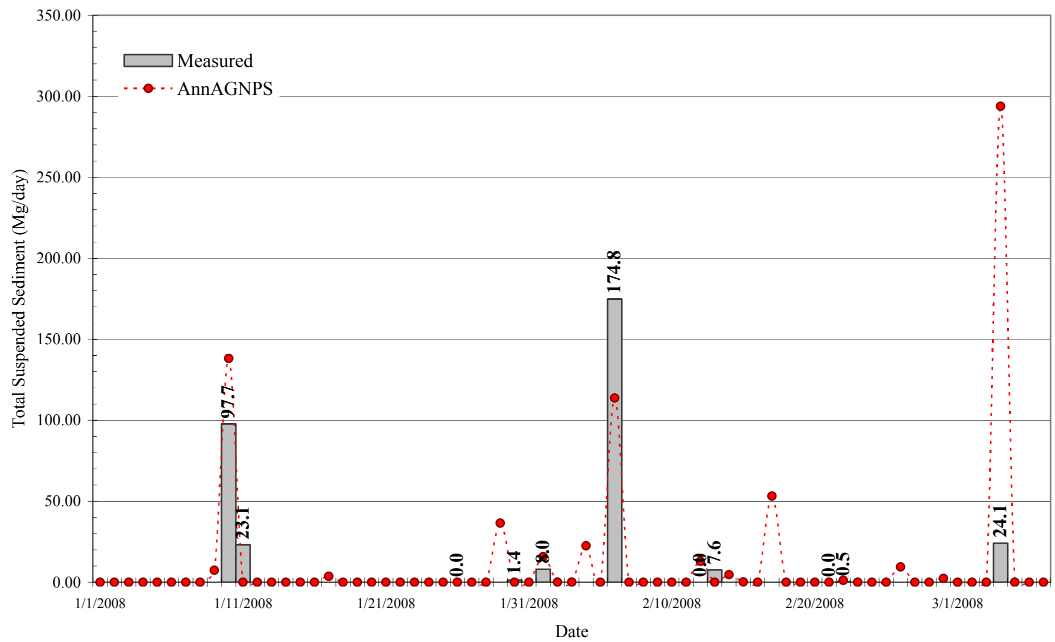


Figure 44: Montgomery Fork measured and predicted suspended sediment.

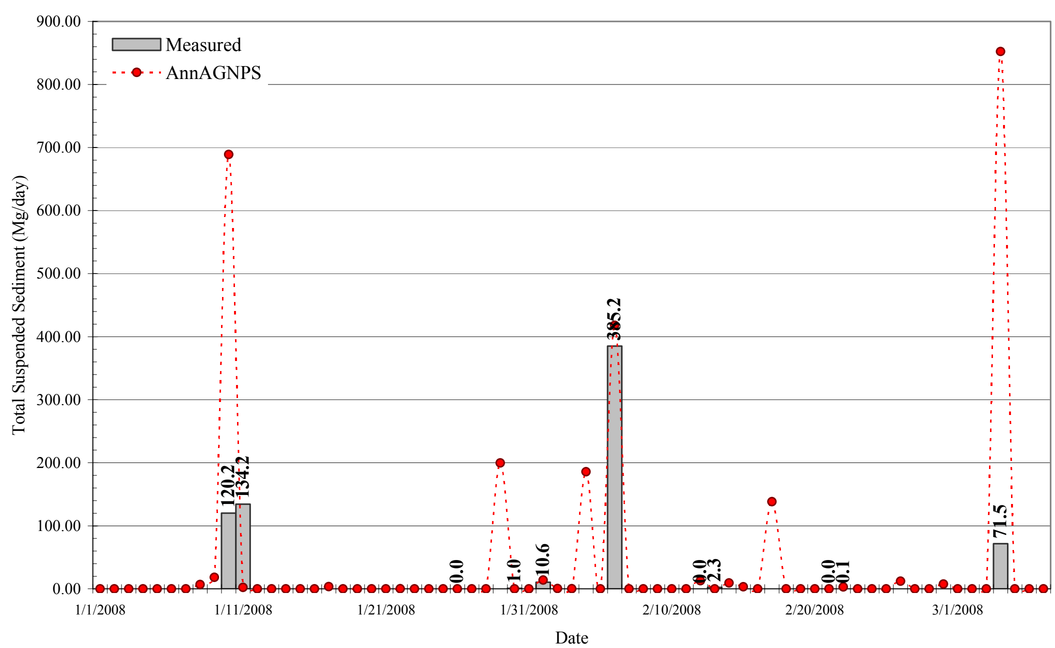


Figure 45: Smokey Creek measured and predicted suspended sediment.

during the spring, summer, and fall of 2007, the AnnAGNPS model provided the sediment yield on average annual values of years 2006 and 2007 at each deposition point.

4.4 Statistical Analysis

It was the objective of this statistical analysis to examine the relationships and correlations of the measured sediment characteristics (percentage of clays, silts, sands, and gravels) found from a grain size particle analysis of 33 different stream bed sediment deposition points collected at all four sub-watersheds of the New River Basin with that of the predicted sediment yield in terms of total weight and percentages of clays, silts, and sands for each location. The different combinations of variables that represent the measured stream bed sediment properties by particle grain size analysis and the annual average value of sediment yield for the drainage area above where the stream bed sediment sample was taken can be seen in Table 19. These variables were placed into the JMP Statistical Software to determine if a correlation exists between the bed sediment found in stream deposition points and the average annual sediment yield on the hillslopes. Note that in Table 19, there are average annual sediment yield variables for years 2006, 2007, and the combination of years 2006 and 2007. The stream bed sediment was collected in the field during the spring, summer, and fall of 2007, and it is thought that these stream bed sediment depositional points contain a historical amount of different amounts of sediment yield for a variable amount of time. Since the stream bed sediment was collected during the months of February through October of 2007, the average annual sediment yield values were included.

Table 19: Statistical variable definitions.

VARIABLES	DEFINITIONS
Site	Site Number of Analysis
Wtashd	Watershed of Site
Area	Drainage Area in Hectares
RGA	Rapid Geomorphic Assessment Score (1-36)
D50	Median Grain Size Diameter from Pebble Count (mm)
D84	84th Largest Grain Size Diameter from Pebble Count (mm)
MP-Cl	Particle Size Distribution - Measured Percent Clay (%)
MP-Si	Particle Size Distribution - Measured Percent Silt (%)
MP-Sa	Particle Size Distribution - Measured Percent Sand (%)
MP-Gr	Particle Size Distribution - Measured Percent Gravel (%)
MS-Cl	Particle Size Distribution - Measured Slope
MS-Si	Particle Size Distribution - Measured Slope
MS-Sa	Particle Size Distribution - Measured Slope
MS-Gr	Particle Size Distribution - Measured Slope
MP-ClSi	Particle Size Distribution - Measured Percent Clay & Silt (%)
MP-SiSa	Particle Size Distribution - Measured Percent Silt & Sand (%)
MP-ClSiSa	Particle Size Distribution - Measured Percent Clay, Silt, & Sand (%)
MP-Cl/Si	Particle Size Distribution - Measured Percent Ratio of Clays to Silts
MP-Cl/Sa	Particle Size Distribution - Measured Percent Ratio of Clays to Sands
MP-Cl/Gr	Particle Size Distribution - Measured Percent Ratio of Clays to Gravels
MP-Si/Cl	Particle Size Distribution - Measured Percent Ratio of Silts to Clays
MP-Si/Sa	Particle Size Distribution - Measured Percent Ratio of Silts to Sands
MP-Si/Gr	Particle Size Distribution - Measured Percent Ratio of Silts to Gravels
MP-Sa/Cl	Particle Size Distribution - Measured Percent Ratio of Sands to Clays
MP-Sa/Si	Particle Size Distribution - Measured Percent Ratio of Sands to Silts
MP-Sa/Gr	Particle Size Distribution - Measured Percent Ratio of Sands to Gravels
MP-Gr/Cl	Particle Size Distribution - Measured Percent Ratio of Gravels to Clays
MP-Gr/Si	Particle Size Distribution - Measured Percent Ratio of Gravels to Silts
MP-Gr/Sa	Particle Size Distribution - Measured Percent Ratio of Gravels to Sands
06-PP-Cl	2006 Annual Average Sediment Yield Predicted Percent Clay (%)
06-PP-Si	2006 Annual Average Sediment Yield Predicted Percent Silt (%)
06-PP-Sa	2006 Annual Average Sediment Yield Predicted Percent Sand (%)
06-PP-ClSi	2006 Annual Average Sediment Yield Predicted Percent Clay & Silt (%)
06-PP-SiSa	2006 Annual Average Sediment Yield Predicted Percent Silt & Sand (%)
06-PW-Cl	2006 Annual Average Sediment Yield Predicted Weight of Clay (Mg)
06-PW-Si	2006 Annual Average Sediment Yield Predicted Weight of Silt (Mg)
06-PW-Sa	2006 Annual Average Sediment Yield Predicted Weight of Sand (Mg)

Table 19 Continued: Statistical variable definitions.

VARIABLES	DEFINITIONS
06-PW-TSY	2006 Predicted Annual Average Sediment Yield (Mg)
06-P-TSY/A	2006 Predicted Annual Average Sediment Yield / Drainage Area (Mg/ha)
06-PW-ClSi	2006 Annual Average Sediment Yield Predicted Weight of Clays and Silts (Mg)
06-PW-SiSa	2006 Annual Average Sediment Yield Predicted Weight of Silts and Sands (Mg)
07-PP-Cl	2007 Annual Average Sediment Yield Predicted Percent Clay (%)
07-PP-Si	2007 Annual Average Sediment Yield Predicted Percent Silt (%)
07-PP-Sa	2007 Annual Average Sediment Yield Predicted Percent Sand (%)
07-PP-ClSi	2007 Annual Average Sediment Yield Predicted Percent Clay & Silt (%)
07-PP-SiSa	2007 Annual Average Sediment Yield Predicted Percent Silt & Sand (%)
07-PW-Cl	2007 Annual Average Sediment Yield Predicted Weight of Clay (Mg)
07-PW-Si	2007 Annual Average Sediment Yield Predicted Weight of Silt (Mg)
07-PW-Sa	2007 Annual Average Sediment Yield Predicted Weight of Sand (Mg)
07-PW-TSY	2007 Predicted Annual Average Sediment Yield (Mg)
07-P-TSY/A	2007 Predicted Annual Average Sediment Yield / Drainage Area (Mg/ha)
07-PW-ClSi	2007 Annual Average Sediment Yield Predicted Weight of Clays and Silts (Mg)
07-PW-SiSa	2007 Annual Average Sediment Yield Predicted Weight of Silts and Sands (Mg)
06+07-PW-Cl	2006 and 2007 Annual Average Sediment Yield Predicted Weight of Clay (Mg)
06+07-PW-Si	2006 and 2007 Annual Average Sediment Yield Predicted Weight of Silt (Mg)
06+07-PW-Sa	2006 and 2007 Annual Average Sediment Yield Predicted Weight of Sand (Mg)
06+07-PW-TSY	2006 and 2007 Predicted Annual Average Sediment Yield (Mg)
06+07-P-TSY/A	2006 and 2007 Predicted Annual Average Sediment Yield / Drainage Area (Mg/ha)

Initially, the variables of interest were checked for outliers and normality. It was noticed that many of the variables used did not seem to represent a strong normal distribution; therefore, a nonparametric analysis was used. From the normal distribution plots, the JMP program suggested four different sites with possible outliers by box plot whiskers analysis. Since a limited amount of data exists for this study, it was decided that no outliers would be declared. All the measured and predicted variables were then placed in a nonparametric multivariate analysis to be used for the distinction of obvious correlations between variables. From the multivariate analysis, there was little correlation noticed among the stream bed sediment and the hillslope sediment yield variables. By comparing the measured with the predicted variables, a table (Table 20) was created to show the top 35 combinations with some correlation. In Table 20, the Spearman's Rho represents the correlation between a combination of variables. The closer Spearman's Rho is to 1.0 or -1.0, the better the correlation. From using the multivariate analysis, there are no strong correlations independently between the measured and predicted variables. Also notice that the smallest p-value is just greater than 0.05 for the combination of different variables. Since there is no combination of measured and predicted variables that have a p-value less than 0.05, there are no significant variables that stand alone for the sediment collected in stream deposition points and the properties of hillslope sediment yield.

From analyzing these sediment deposits and hillslope sediment yield, there seems to be some slight relationship between the two, and a lack of data may possibly establish more significance or correlation between the two. To further analyze the stream bed

Table 20: Best nonparametric multivariate sediment relationships found.

Nonparametric Multivariate Analysis				
Number	Variable	by Variable	Spearman ρ	Prob>|ρ|
1	06+07-PW-Cl	MP-Gr/Sa	-0.341	0.052
2	06+07-PW-Cl	MP-Gr/Si	-0.341	0.052
3	06+07-PW-Cl	MP-Sa/Gr	0.341	0.052
4	06+07-PW-Cl	MP-SiSa	0.335	0.057
5	07-PW-Cl	MP-Gr/Sa	-0.335	0.057
6	07-PW-Cl	MP-Gr/Si	-0.335	0.057
7	07-PW-Cl	MP-Sa/Gr	0.335	0.057
8	07-PW-Cl	MP-Si/Gr	0.334	0.057
9	06-PW-Cl	MP-Gr/Sa	-0.332	0.059
10	06-PW-Cl	MP-Gr/Si	-0.332	0.059
11	06-PW-Cl	MP-Sa/Gr	0.332	0.059
12	06+07-PW-Cl	MP-Gr	-0.332	0.059
13	06+07-PW-Cl	MP-ClSiSa	0.329	0.062
14	07-PW-Cl	MP-SiSa	0.329	0.062
15	07-PW-Cl	MP-Gr	-0.326	0.064
16	06-PW-Cl	MP-SiSa	0.326	0.065
17	06+07-PW-Cl	MP-Sa	0.325	0.065
18	06+07-PW-Cl	MS-Sa	0.325	0.065
19	06-PW-Si	MP-Gr/Sa	-0.324	0.066
20	06-PW-Si	MP-Gr/Si	-0.324	0.066
21	06-PW-Si	MP-Sa/Gr	0.324	0.066
22	07-PW-Cl	MP-ClSiSa	0.323	0.067
23	06-PW-Cl	MP-Gr	-0.322	0.067
24	07-PW-TSY	MP-Si/Gr	0.322	0.068
25	07-PP-ClSi	MP-Si/Gr	0.322	0.068
26	06+07-PW-Cl	MP-Si/Gr	0.320	0.069
27	07-PP-SiSa	MP-Si/Gr	0.320	0.070
28	06-PW-Si	MP-Si/Gr	0.320	0.070
29	06-PW-Cl	MP-ClSiSa	0.319	0.070
30	07-PW-TSY	MP-Gr/Sa	-0.319	0.071
31	07-PW-TSY	MP-Gr/Si	-0.319	0.071
32	07-PW-TSY	MP-Sa/Gr	0.319	0.071
33	06-PW-TSY	MP-Si/Gr	0.319	0.071
34	07-PW-Cl	MP-Sa	0.317	0.072
35	07-PW-Cl	MS-Sa	0.317	0.072

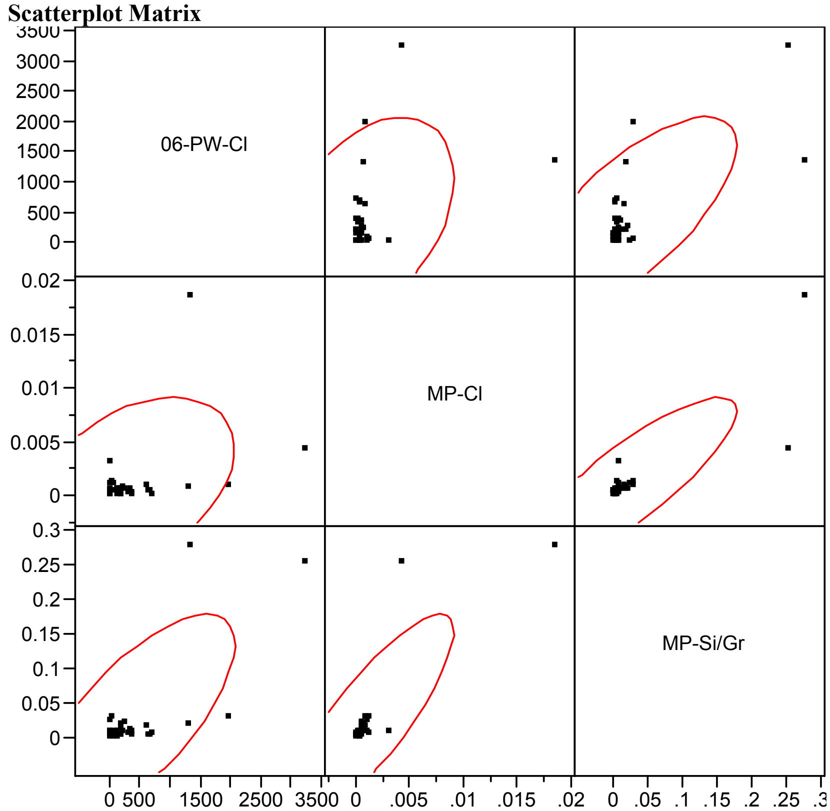
sediment deposit and yield properties with the best correlation and relationship, a Stepwise Regression Model was used in JMP to see if there was a better relationship between the measured sediment deposit characteristics and the sediment yield when multiple variables are used together. Using the stepwise regression model through standard least squares analysis, four sediment yield variables produced from the AnnAGNPS model output created a significant relationship with pairs of different stream bed sediment deposit variables.

The four different dependant variables were the predicted sediment yield weight of clay (PW-Cl), predicted sediment yield weight of silt (PW-Si), predicted total sediment yield weight (PW-TSY), and the predicted weight of clays and silts combined (PW-ClSi). Each of these dependant variables contained a significant relationship with a combination of two predictor variables measured in the particle grain size analysis of the stream bed sediment deposits. Of the stream bed sediment variables that established a significant relationship with different average annual hillslope sediment yield variables, the particle size distribution slopes for clays, silts, sands, and gravels did not provide a significant correlation or relationship with annual average hillslope sediment yield. Therefore, the essential stream bed sediment variables are the percentages of different sediment size classifications found in each sample. The multivariate analysis of these four dependant variables with their related independent measured variables can be seen in Figures 46 through 49. Using the JMP Stepwise Regression tool, the PW-Cl, PW-Si, PW-TSY, and PW-ClSi for years 2006, 2007, and the combination of the two were used to define a relationship with the set of measured particle size classifications found at each sediment

Multivariate Correlations

	06-PW-Cl	MP-Cl	MP-Si/Gr
06-PW-Cl	1.0000	0.3854	0.7214
MP-Cl	0.3854	1.0000	0.8435
MP-Si/Gr	0.7214	0.8435	1.0000

Scatterplot Matrix



Nonparametric: Spearman's ρ

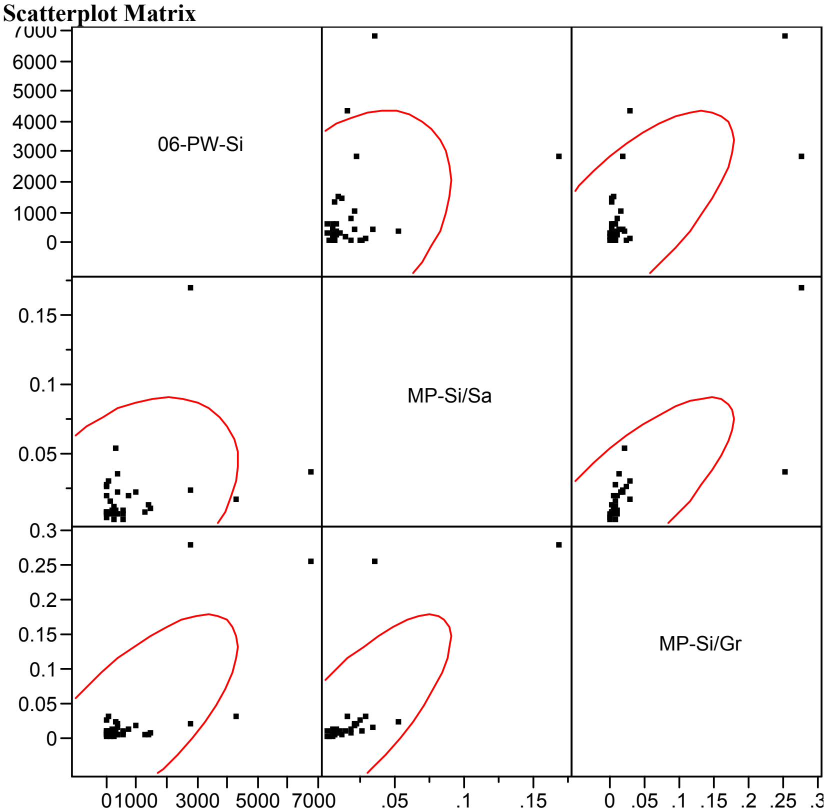
Variable	by Variable	Spearman ρ	Prob>|ρ|
MP-Cl	06-PW-Cl	0.1228	0.4961
MP-Si/Gr	06-PW-Cl	0.3108	0.0783
MP-Si/Gr	MP-Cl	0.7174	<.0001

Figure 46: Nonparametric multivariate results for 06-PW-Cl.

Multivariate Correlations

	06-PW-Si	MP-Si/Sa	MP-Si/Gr
06-PW-Si	1.0000	0.3414	0.7206
MP-Si/Sa	0.3414	1.0000	0.7874
MP-Si/Gr	0.7206	0.7874	1.0000

Scatterplot Matrix



Nonparametric: Spearman's ρ

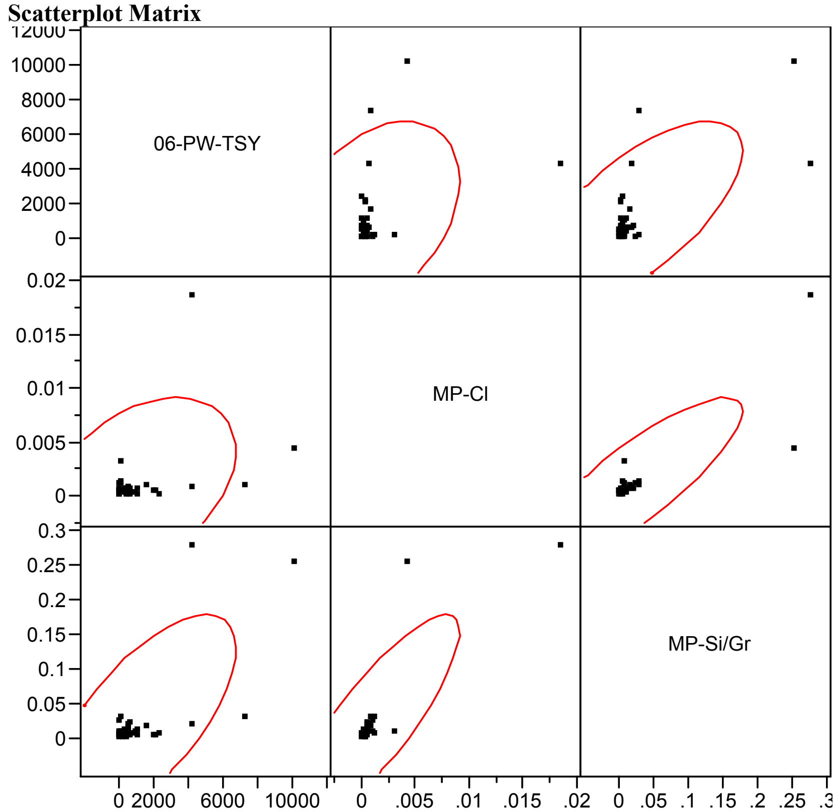
Variable	by Variable	Spearman ρ	Prob>|ρ|
MP-Si/Sa	06-PW-Si	0.3038	0.0856
MP-Si/Gr	06-PW-Si	0.3195	0.0699
MP-Si/Gr	MP-Si/Sa	0.7938	<.0001

Figure 47: Nonparametric multivariate results for 06-PW-Si.

Multivariate Correlations

	06-PW-TSY	MP-Cl	MP-Si/Gr
06-PW-TSY	1.0000	0.3681	0.6917
MP-Cl	0.3681	1.0000	0.8435
MP-Si/Gr	0.6917	0.8435	1.0000

Scatterplot Matrix



Nonparametric: Spearman's ρ

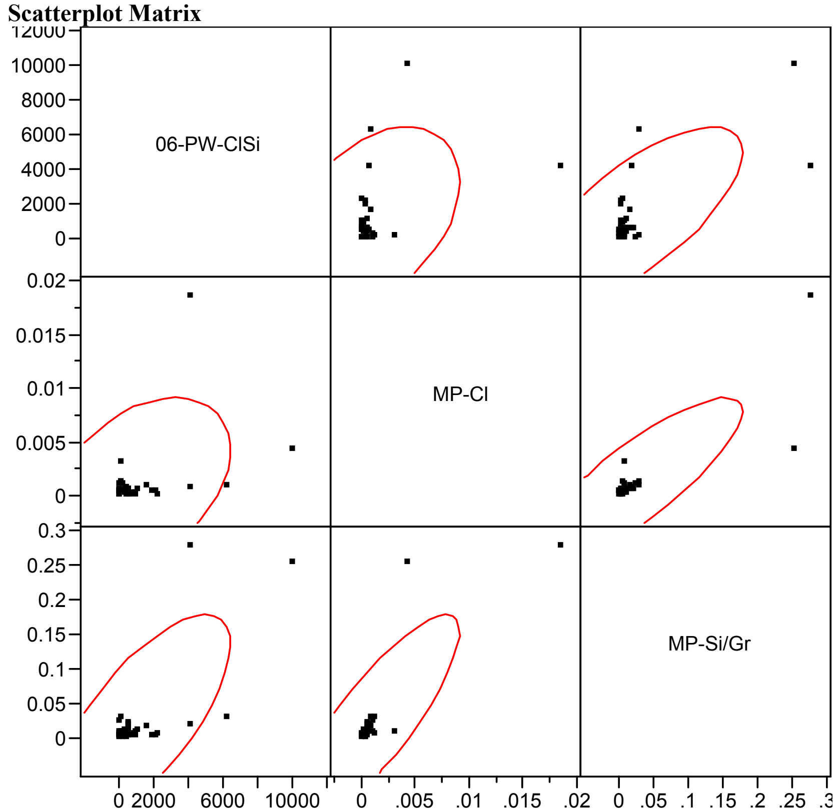
Variable	by Variable	Spearman ρ	Prob>|ρ|
MP-Cl	06-PW-TSY	0.1139	0.5280
MP-Si/Gr	06-PW-TSY	0.3189	0.0705
MP-Si/Gr	MP-Cl	0.7174	<.0001

Figure 48: Nonparametric multivariate results for 06-PW-TSY.

Multivariate Correlations

	06-PW-ClSi	MP-Cl	MP-Si/Gr
06-PW-ClSi	1.0000	0.3879	0.7212
MP-Cl	0.3879	1.0000	0.8435
MP-Si/Gr	0.7212	0.8435	1.0000

Scatterplot Matrix



Nonparametric: Spearman's ρ

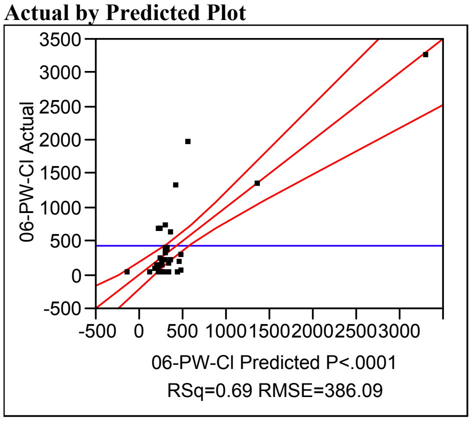
Variable	by Variable	Spearman ρ	Prob>|ρ|
MP-Cl	06-PW-ClSi	0.1122	0.5341
MP-Si/Gr	06-PW-ClSi	0.3112	0.0780
MP-Si/Gr	MP-Cl	0.7174	<.0001

Figure 49: Nonparametric multivariate results for 06-PW-ClSi .

deposition point in the stream. Interestingly enough, the same measured variables for the stream bed sediment deposits contained a similar relationship to the PW-Cl, PW-Si, PW-TSY, and PW-ClSi for both of the years 2006 and 2007, as well as the combination of the two. Since these relationships between the measured stream bed sediment and the predicted sediment yield are similar for the three sets of years, it was decided that this statistical analysis would primarily focus on the 2006 AnnAGNPS sediment yield variables that showed an association with a few of the measured stream bed sediment deposit variables. It is also worth noting that since the fine bed sediment collected in stream deposition points was obtained during the middle of 2007 and the sediment deposits should contain historical properties of hillslope and channel erosion, the 2006 sediment yield should be a more appropriate time frame to be compared with the measured data. Using the four 2006 predicted sediment yield variables in a regression analysis, a pair of measured sediment deposit characteristics seemed to provide a better relationship than the single combination of the measured versus predicted sediment values previously seen in the multivariate analysis. Figures 50 through 57 show the different model relationships observed by regression analysis for predicted average annual sediment yield and various measured sediment deposit characteristics.

After reviewing over all the stepwise standard least squares regression analysis results with the various stream bed sediment deposition properties and the average annual hillslope sediment yield properties, there seems to be a much better correlation and significance for the assembly of multiple variables combined than just one single pair of measured and predicted values as shown summarized in Table 21.

Response 06-PW-Cl
Whole Model
Actual by Predicted Plot



Summary of Fit

RSquare	0.693024
RSquare Adj	0.672559
Root Mean Square Error	386.0925
Mean of Response	420.4902
Observations (or Sum Wgts)	33

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	10095969	5047985	33.8638
Error	30	4472024	149067	Prob > F
C. Total	32	14567993		<.0001

Parameter Estimates

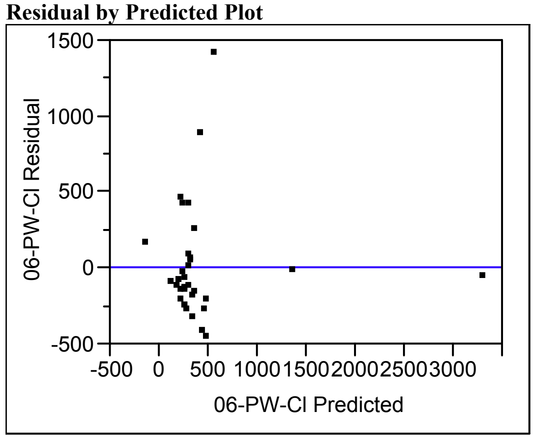
Term	Estimate	Std Error	t Ratio	Prob>|t|	Lower 95%	Upper 95%	VIF
Intercept	254.13227	72.63989	3.50	0.0015	105.78184	402.48271	.
MP-Cl	-162109.9	39475.45	-4.11	0.0003	-242729.5	-81490.23	3.4660464
MP-Si/Gr	14819.32	2031.528	7.29	<.0001	10670.386	18968.253	3.4660464

Durbin-Watson

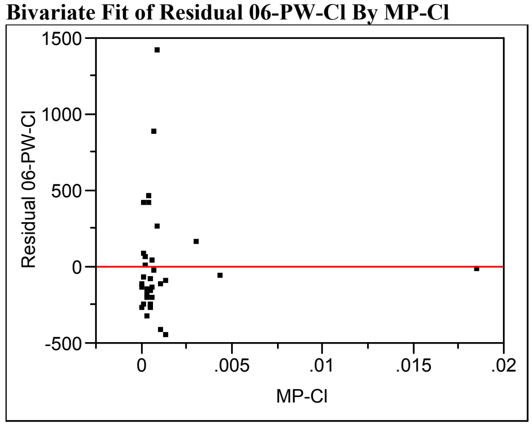
Durbin-Watson	Number of Obs.	AutoCorrelation
1.8618406	33	0.0624

Figure 50: 2006 average annual sediment yield clay weight regression model.

Residual by Predicted Plot



Bivariate Fit of Residual 06-PW-Cl By MP-Cl



Bivariate Fit of Residual 06-PW-Cl By MP-Si/Gr

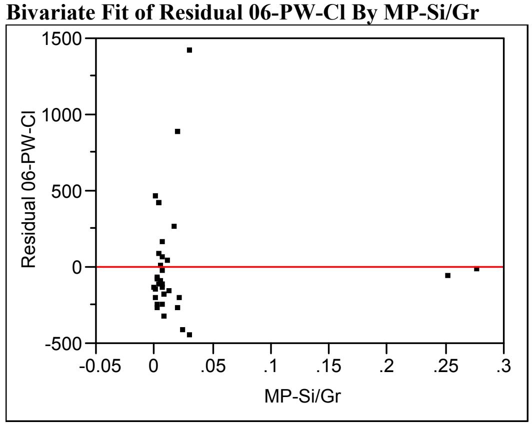
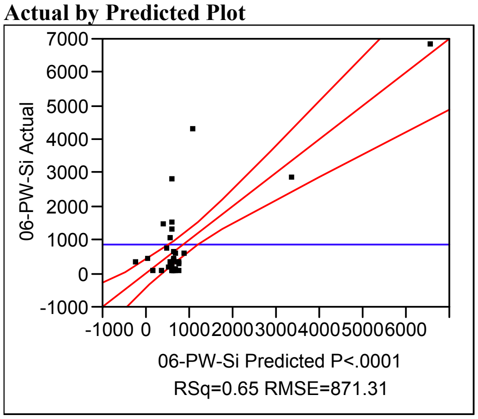


Figure 51: 2006 average annual sediment yield clay weight residual plots.

Response 06-PW-Si
Whole Model
Actual by Predicted Plot



Summary of Fit

RSquare	0.653622
RSquare Adj	0.63053
Root Mean Square Error	871.31
Mean of Response	842.8009
Observations (or Sum Wgts)	33

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	42977593	21488797	28.3052
Error	30	22775435	759181.17	Prob > F
C. Total	32	65753028		<.0001

Parameter Estimates

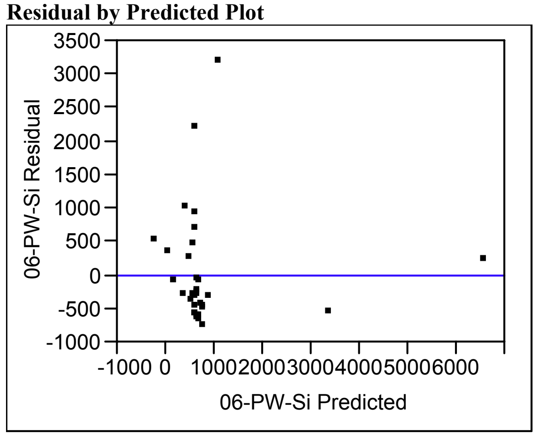
Term	Estimate	Std Error	t Ratio	Prob>|t|	Lower 95%	Upper 95%	VIF
Intercept	718.00424	183.0249	3.92	0.0005	344.21753	1091.791	.
MP-Si/Sa	-29125.19	8535.869	-3.41	0.0019	-46557.76	-11692.62	2.6318192
MP-Si/Gr	27247.061	3994.983	6.82	<.0001	19088.217	35405.905	2.6318192

Durbin-Watson

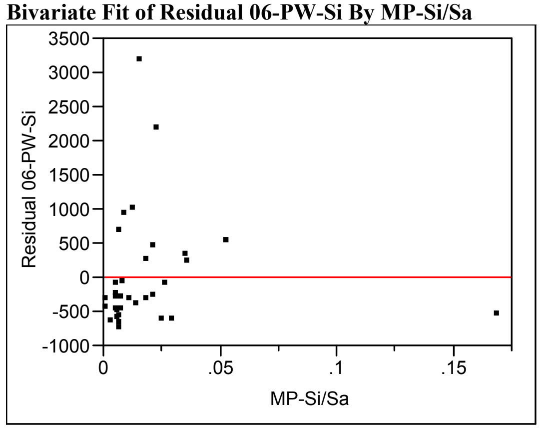
Durbin-Watson	Number of Obs.	AutoCorrelation
2.1055523	33	-0.0606

Figure 52: 2006 average annual sediment yield silt weight regression model.

Residual by Predicted Plot



Bivariate Fit of Residual 06-PW-Si By MP-Si/Sa



Bivariate Fit of Residual 06-PW-Si By MP-Si/Gr

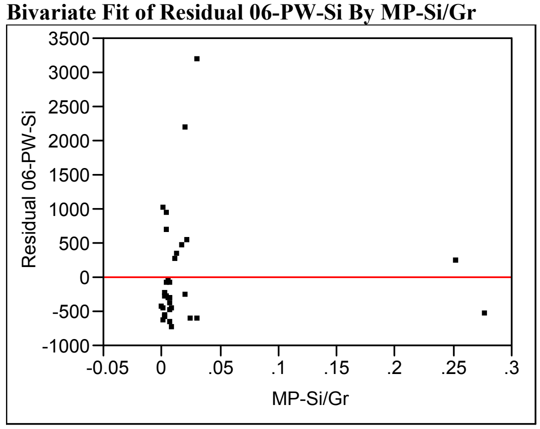
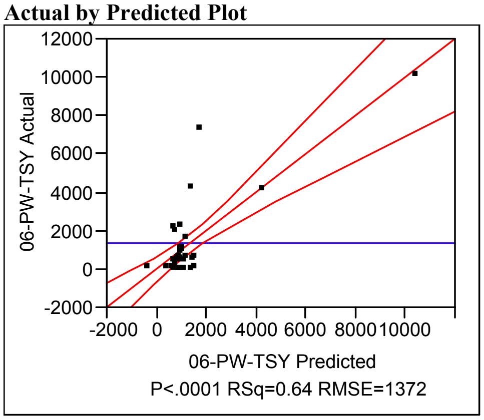


Figure 53: 2006 average annual sediment yield silt weight residual plots.

Response 06-PW-TSY
Whole Model
Actual by Predicted Plot



Summary of Fit

RSquare	0.639185
RSquare Adj	0.615131
Root Mean Square Error	1371.97
Mean of Response	1321.079
Observations (or Sum Wgts)	33

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	100035223	50017611	26.5726
Error	30	56469065	1882302.2	Prob > F
C. Total	32	156504288		<.0001

Parameter Estimates

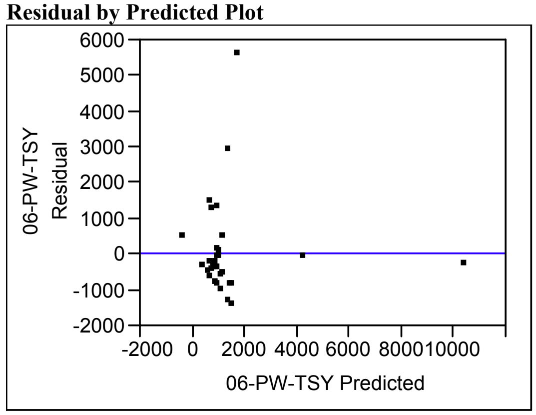
Term	Estimate	Std Error	t Ratio	Prob>|t|	Lower 95%	Upper 95%	VIF
Intercept	798.7942	258.124	3.09	0.0042	271.63465	1325.9538	.
MP-Cl	-512783.3	140275	-3.66	0.0010	-799263.2	-226303.5	3.4660464
MP-Si/Gr	46716.336	7218.984	6.47	<.0001	31973.205	61459.468	3.4660464

Durbin-Watson

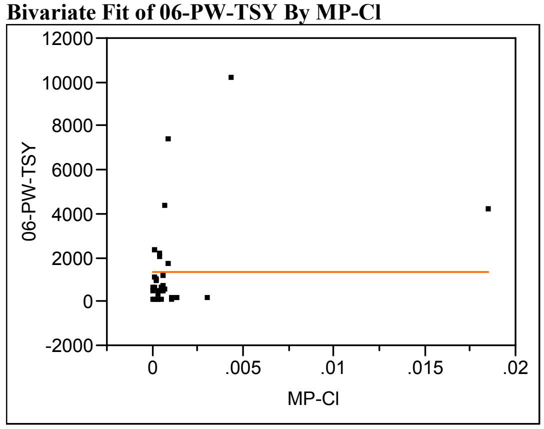
Durbin-Watson	Number of Obs.	AutoCorrelation
1.8883167	33	0.0478

Figure 54: 2006 average annual total sediment yield regression model.

Residual by Predicted Plot



Bivariate Fit of 06-PW-TSY By MP-Cl



Bivariate Fit of 06-PW-TSY By MP-Si/Gr

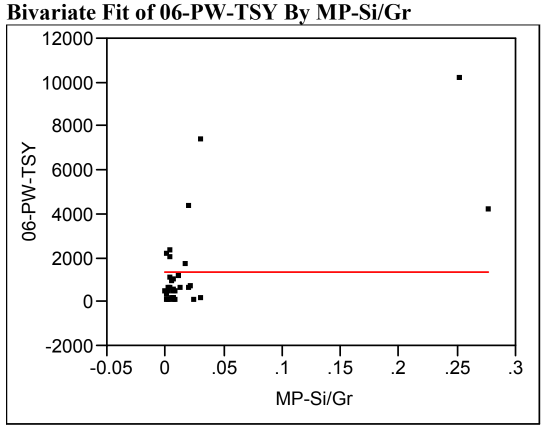
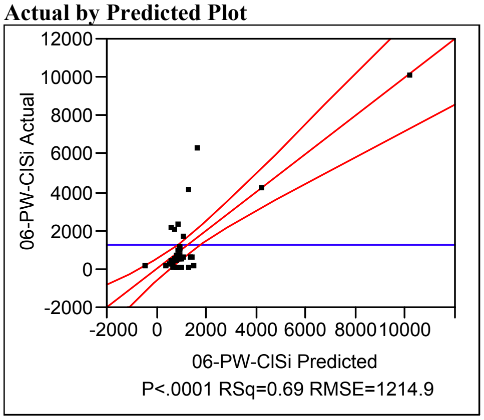


Figure 55: 2006 average annual total sediment yield residual plots.

Response 06-PW-ClSi
Whole Model
Actual by Predicted Plot



Summary of Fit

RSquare	0.688396
RSquare Adj	0.667623
Root Mean Square Error	1214.857
Mean of Response	1263.291
Observations (or Sum Wgts)	33

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	97815431	48907716	33.1380
Error	30	44276352	1475878.4	Prob > F
C. Total	32	142091783		<.0001

Parameter Estimates

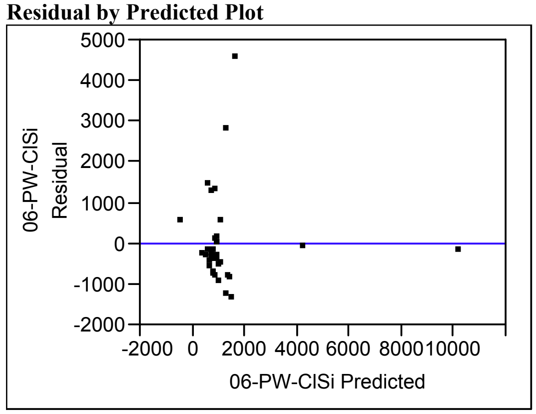
Term	Estimate	Std Error	t Ratio	Prob>|t|	Lower 95%	Upper 95%	VIF
Intercept	742.98869	228.5646	3.25	0.0028	276.19744	1209.7799	.
MP-Cl	-500024.1	124211.3	-4.03	0.0004	-753697.4	-246350.9	3.4660464
MP-Si/Gr	46001.313	6392.293	7.20	<.0001	32946.509	59056.117	3.4660464

Durbin-Watson

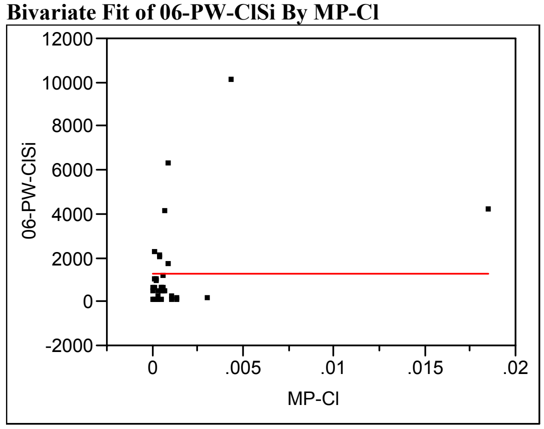
Durbin-Watson	Number of Obs.	AutoCorrelation
1.8558222	33	0.0621

Figure 56: 2006 average annual clay and silt sediment yield regression model.

Residual by Predicted Plot



Bivariate Fit of 06-PW-ClSi By MP-Cl



Bivariate Fit of 06-PW-ClSi By MP-Si/Gr

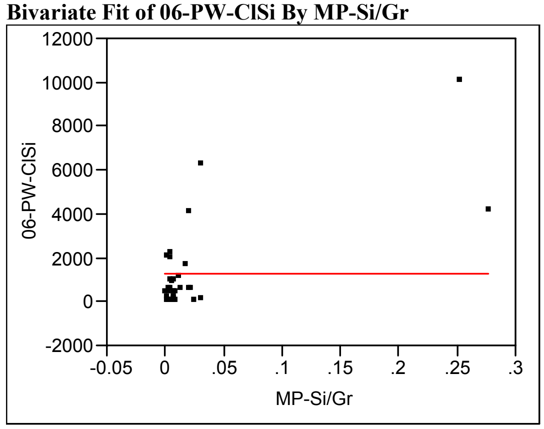


Figure 57: 2006 average annual clay and silt sediment yield residual plots.

Table 21: Summary of statistical relationships for sediment deposition and yield.

Sediment Yield	Stream Bed	Multivariate		Standard Least Squares Regression		
Response Variable	Sediment Variables	Spearman ρ	Prob > |ρ|	R-Square	F Ratio	Prob > F
06-PW-Cl	MP-Cl	0.1228	0.4961	0.69	33.86	< 0.0001
	MP-Si/Gr	0.3108	0.0783			
06-PW-Si	MP-Si/Sa	0.3038	0.0856	0.65	28.31	< 0.0001
	MP-Si/Gr	0.3195	0.0699			
06-PW-TSY	MP-Cl	0.1139	0.5280	0.64	26.57	< 0.0001
	MP-Si/Gr	0.3189	0.0705			
06-PW-ClSi	MP-Cl	0.1122	0.5341	0.69	33.14	< 0.0001
	MP-Si/Gr	0.3112	0.0780			

For the PW-Cl, PW-TSY, and PW-ClSi variables, the two best response variables were the MP-Cl and MP-Si/Gr. With the PW-Si variable, the two response variables were MP-Si/Sa and MP-Si/Gr. The four stepwise regression equations created from the combination of stream bed sediment variables to predict a hillslope sediment yield variable are shown in equations 12 through 15.

$$\mathit{06\text{-}PW\text{-}Cl} = 254.13 - 162{,}109.87(\mathit{MP\text{-}Cl}) + 14{,}819.32(\mathit{MP\text{-}Si/Gr}) \tag{12}$$

$$\mathit{06\text{-}PW\text{-}Si} = 718.01 - 29{,}125.19(\mathit{MP\text{-}Si/Sa}) + 27{,}247.06(\mathit{MP\text{-}Si/Gr}) \tag{13}$$

$$\mathit{06\text{-}PW\text{-}TSY} = 798.79 - 512{,}783.35(\mathit{MP\text{-}Cl}) + 46{,}716.34(\mathit{MP\text{-}Si/Gr}) \tag{14}$$

$$\mathit{06\text{-}PW\text{-}ClSi} = 742.99 - 500{,}024.15(\mathit{MP\text{-}Cl}) + 46{,}001.31(\mathit{MP\text{-}Si/Gr}) \tag{15}$$

It's interesting to note that the measured ratio of silt to gravel seems to be a sediment deposition variable in the four stepwise models that contained an overall and individual p-value that was below 0.05, which showed a significant relationship between the variables placed in the stepwise regression model. Also note that in the four regression models shown, the VIF values were less than 10, which indicated that there were no major multicollinearity problems with the variables used. For all four of the models, the confidence interval does not contain a zero value, which would show that a variable would not have a significant relationship with the other values used in the model. The best R-square value showed to be 0.69 with the PW-Cl and PW-ClSi, while the lowest R-square value came from the PW-TSY at 0.64. These R-square values show that the sediment data used contains a good bit of variability, which is expected with measuring sediment characteristics. If viewed closely, the standard least squares regression plots reveal a leverage effect due to a possible outlier in the data. It is unclear with the limited amount of data available that this data point is an outlier or is acceptable.

Overall, the statistics of sediment from channel deposition points in the stream with the average annual sediment yield on the hillslope of all the sites contained in all four watersheds show that there is a significant relationship with clays, silts, sands, and gravels. More data would probably produce less variability and possibly a better prediction model with the stream sediment deposits and hillslope sediment yield on an average annual basis.

Chapter 5: Discussion

5.1 Conclusions

After many hours of gathering data as input parameters into the AnnAGNPS pollutant model and assigning many NRCS TR-55 and RUSLE variables to the different land uses and soils types within the four different sub-watersheds located in the New River Basin, the AnnAGNPS program provided a daily estimate of the runoff and sediment yield that consistently emulated that of the actual measured data collected for this study. As seen from previous plots and tabular data presented in the results section of this analysis, the AnnAGNPS pollutant model consistently over-predicted the peak flow at the outlet of each sub-watershed. The AnnAGNPS pollutant loading model is not a stranger to problems with peak flow overestimation. As shown by other AnnAGNPS studies, the peak flow rate is usually overestimated (Shrestha et al., 2006; Licciardello, et al., 2007; Sarangi et al., 2007). The AnnAGNPS's ability to correctly identify the peak flow rate for an area is largely a product of the rainfall distribution selected for the area through the hydrologic NRCS TR-55 computations. Licciardello et al. (2007) suggest using a different rainfall distribution for a certain area to improve the model's peak flow performance. The four different sub-watersheds analyzed seem to have a much steeper topography than the majority of published AnnAGNPS modeling studies, which may influence some error into the simulations of runoff and sediment yield.

Due to a lack of time, finance, and personnel used in this study, there was only a one full climate station just outside of New River Basin, and four tipping bucket rain gauges near each study site that was used to calibrate the AnnAGNPS pollutant loading model. With the limited amount of precipitation data available for this study, the AnnAGNPS pollutant loading model produced daily runoff amounts per storm event that usually paralleled the measured runoff amount estimated from stage recorders placed near the outlet of the sub-watersheds. The AnnAGNPS pollutant loading model also produced acceptable daily sediment yields that similarly matched the total suspended solids concentrations at the outlet of each sub-watershed.

From discussions with the creators of the AnnAGNPS model, there would need to be more weather stations and precipitation gauges in and around the watersheds to provide better runoff and sediment yield results. Due to the size and terrain of the sub-watersheds in this study, it was suggested by the creators of the AnnAGNPS model that at least five precipitation gauges should have been placed at different elevations and locations in each sub-watershed in conjunction to the full climate station at the Big South Fork National River and Recreation Area. Due to programming a series of different parameters with four different models, it became apparent that in this mountainous terrain, the precipitation amount can vary over a small area, which can greatly influence the model's results. Precipitation input into the program is definitely a lacking variable that would need to be improved to create a more accurate model for the New River Basin.

Overall, it is very hard to have a computer model precisely mimic the chaos and constant variations of hydrology and sediment transport on a watershed scale. From the results demonstrated by the AnnAGNPS pollutant loading model, it has been demonstrated that the AnnAGNPS pollutant loading model has the potential to be used in a mountainous, rural, forested landscape for the usage of general watershed management with variations of runoff and sediment yield from various alterations of land use disturbances such as logging, surface mining, and urbanization. Still, the use of the AnnAGNPS model in non-agricultural watersheds must be used with much caution. For example, the user must create a unique set of Manning's n coefficients, curve numbers, and cover management values to properly capture the current amount of sediment yield released by a variety of different land use disturbances for mountainous, non-agricultural environments. Related to the hesitation of using the model in non-agricultural environments, Sarangi et al. (2007) state that the AnnAGNPS pollutant loading model performed poorly in a forested environment as compared to an agricultural environment where established runoff and sediment yield values are available. If the land use curve numbers are slightly manipulated to better represent a forested environment through calibration techniques used in the analysis with the New River sub-watersheds, instead of using standard textbook values suggested for forest environments like that of Sarangi et al. (2007), the AnnAGNPS pollutant loading model can better produce runoff in an forested environment which does not contain a large amount of agricultural activities. But in agreement with Sarangi et al., the AnnAGNPS pollutant loading model does seem to present some difficulties in an environment largely occupied by forests. In comparison to other procudures in estimating the sediment yield occurring on different hillslopes, the AnnAGNPS pollutant loading model, though just a computer model, seems to accurately estimate the annual average sediment yield from variety of land use disturbances, soils, climate, and terrain consistently.

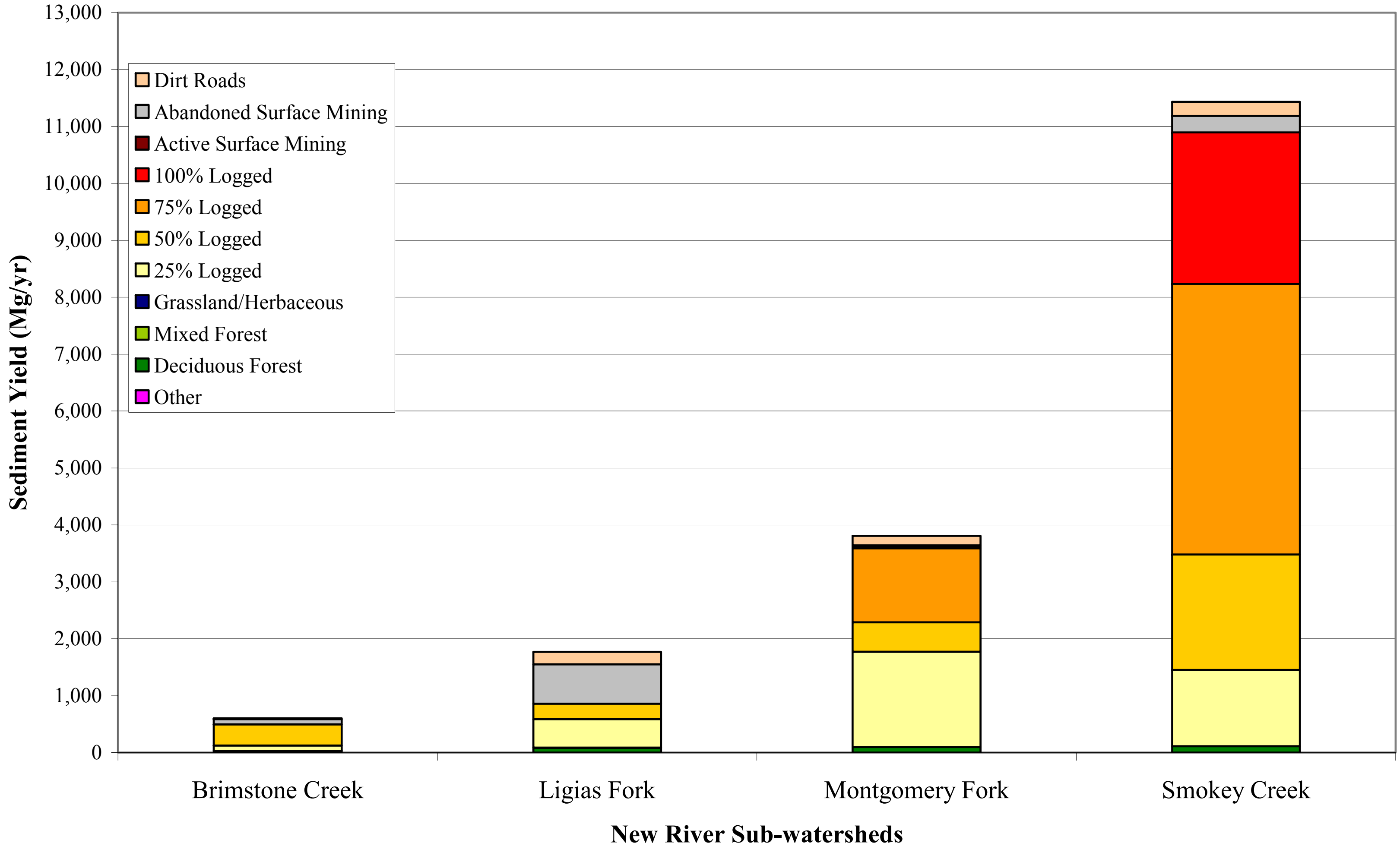
There are many factors that arise when attempting to predict the amount of sediment yield based on large areas defined by one land use application. For instance, the Ligias Fork measured total suspended solids and the AnnAGNPS predicted sediment yield contained a large percent difference for the month of February and March 2008, with the measured sediment concentration being much larger than that of the model's prediction. A major variable that caused a noticeable increase in the measured suspended sediment during February and March for Ligias Fork was likely due to utility construction (as seen in Figures 58 & 59) that did not take enough preventative efforts to keep exposed soil from entering Ligias Fork, which flowed parallel to the utility construction on the highway.

This temporary direct input of sediment into the stream during large storm events would not be predicted by AnnAGNPS pollutant loading model or any other computer software available on a watershed scale. The multitude of dirt roads would not have been used as a dominant sediment source in the AnnAGNPS pollutant loading program if it were normally used. From several field investigations into the different sectors of the

Figures 58 & 59: Temporary sediment yield increase due to utility construction.

New River Basin, it was apparent that the dirt roads seemed to cause a noticeable amount of sedimentation into the streams; therefore, the program's classical gully command was manipulated to account for these features.

The summarized annual average sediment yield results produced by AnnAGNPS for each sub-watershed's land use disturbances are shown in Figures 60 through 68 with the location of different average annual sediment yield amounts seen in Figures 69-72 for the AnnAGNPS flow cell areas. Figure 60 is a stacked bar chart which collectively provides the amount of average annual sediment yield from each of the four sub-watersheds of interest in the New River Basin. Figure 60 shows the major land use disturbances that seem to be generating excessive sedimentation to the local streams. For Figures 61-68, there are two different pie charts seen for each sub-watershed. The annual average sediment yield pie chart that has units in mega-grams per year (Mg/yr) shows the types of land use in the entire watershed that contribute to the area's average sediment budget. This pie chart is useful in understanding the amount of sediment that being transported from the watershed. Note that the pie chart in Mg/yr can also be misleading because the land use areas are not normalized by the percentage of area occupied in the sub-watershed. To compare the different land use types with the amount of annual average sediment yield estimated by the AnnAGNPS pollutant loading model, the second pie chart is supplied for each sub-watershed, which contains units of Mg/ha/yr. This second pie chart can be used to compare the amount of sediment yield occurring from a normalized area.



1 Mega-gram (Mg) = 1 Metric Ton

Figure 60: Average annual sediment yield for all sub-watersheds (Mg/yr). (2006)

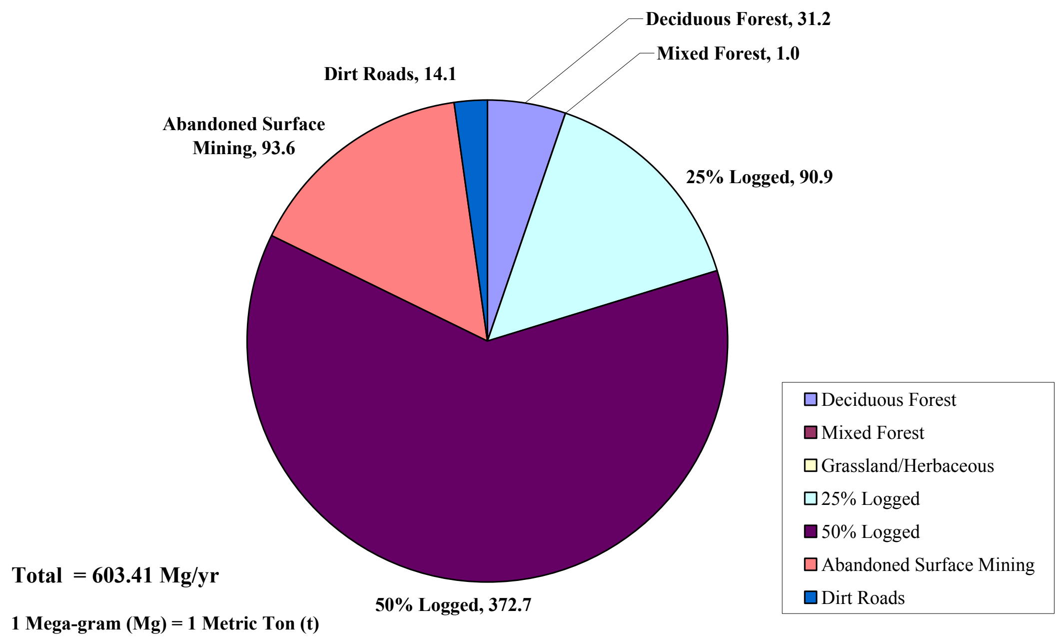


Figure 61: Brimstone Creek average annual sediment yield (Mg/yr). (2006)

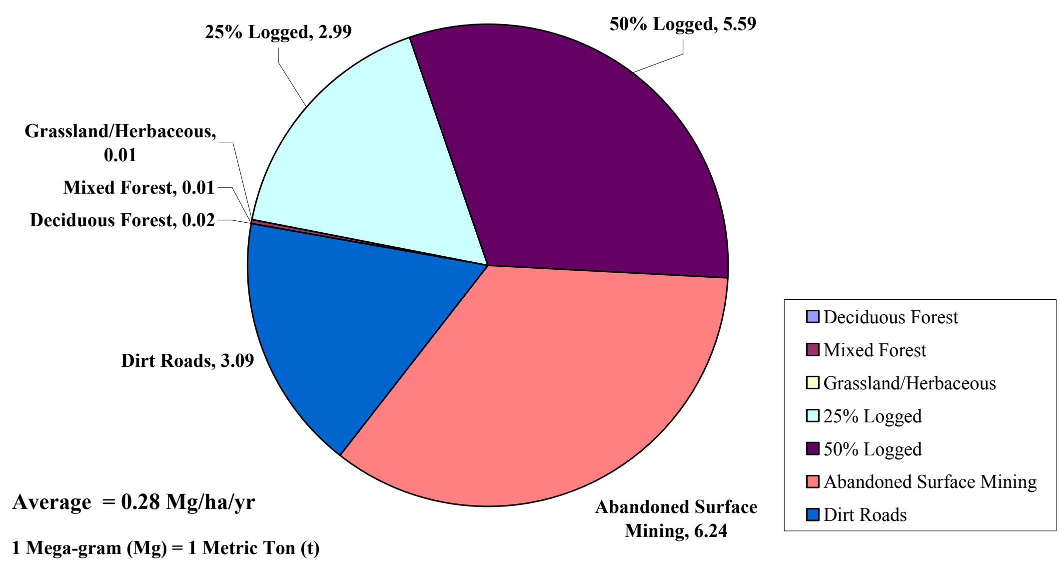


Figure 62: Brimstone Creek normalized annual sediment yield (Mg/ha/yr). (2006)

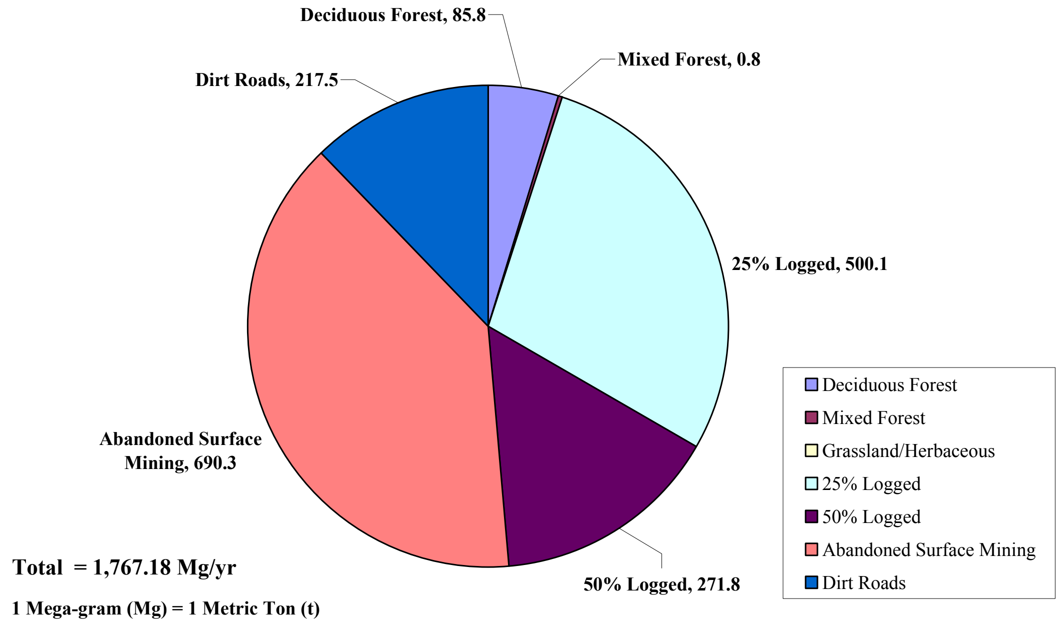


Figure 63: Ligias Fork average annual sediment yield (Mg/yr). (2006)

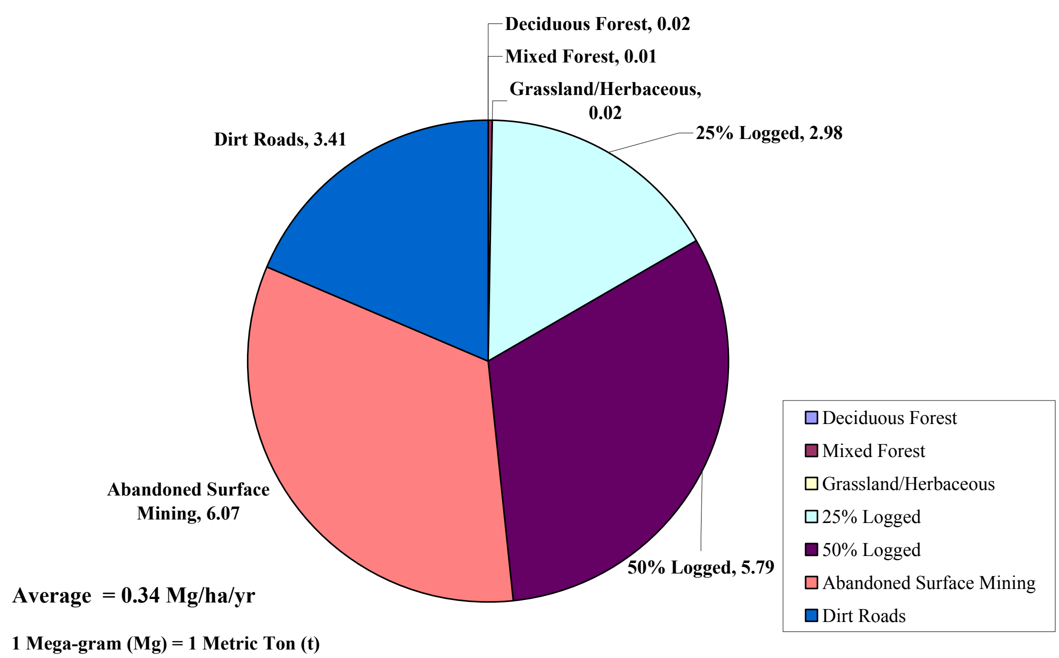


Figure 64: Ligias Fork normalized average annual sediment yield (Mg/ha/yr). (2006)

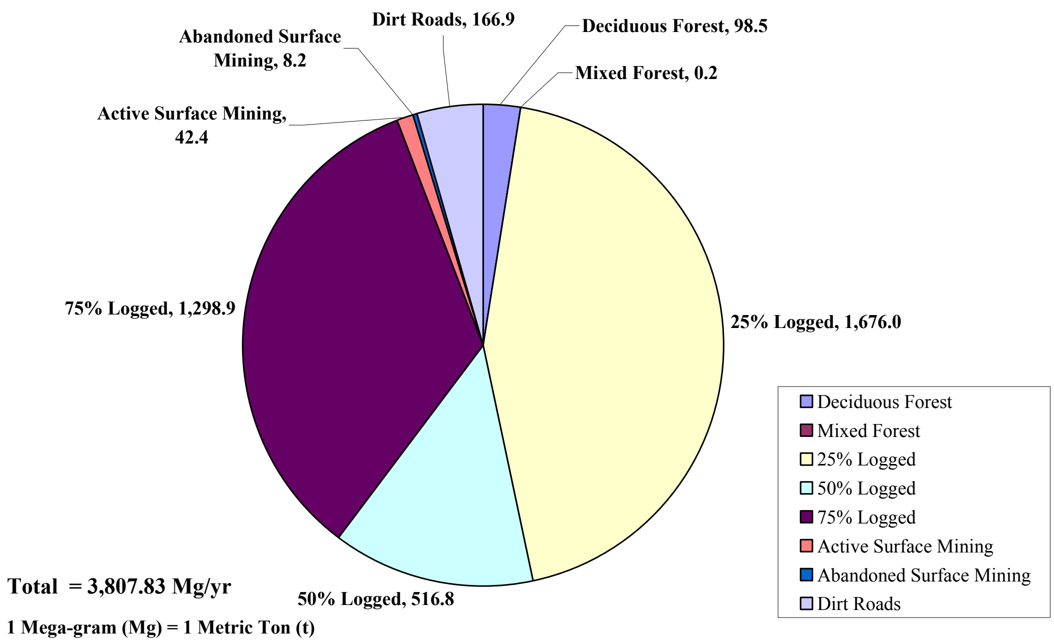


Figure 65: Montgomery Fork average annual sediment yield (Mg/yr). (2006)

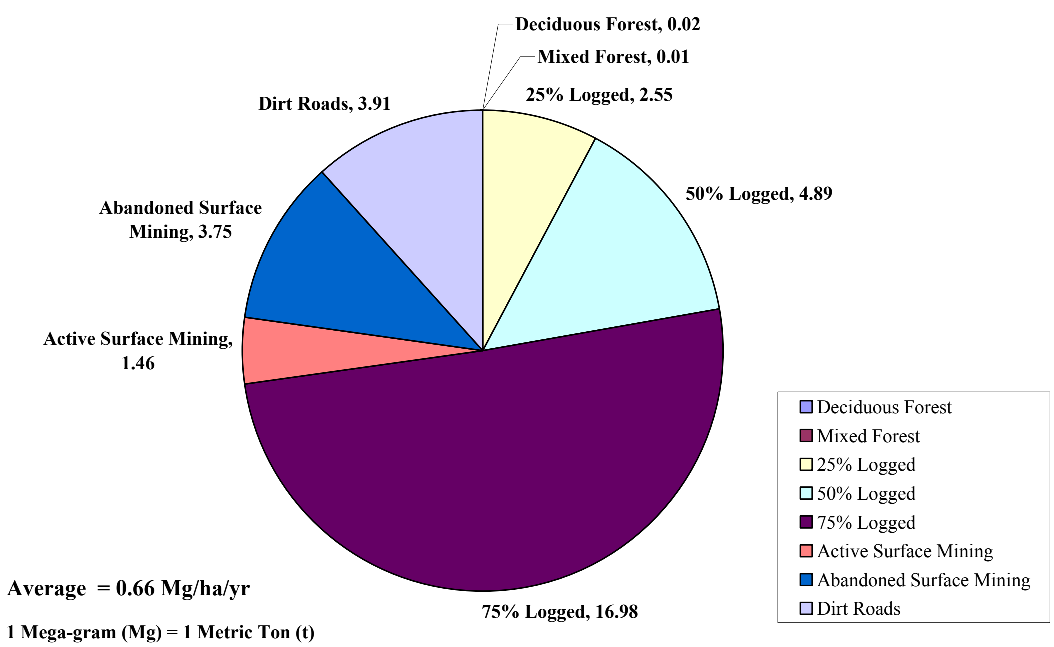


Figure 66: Montgomery Fork normalized average annual sediment yield (Mg/ha/yr). (2006)

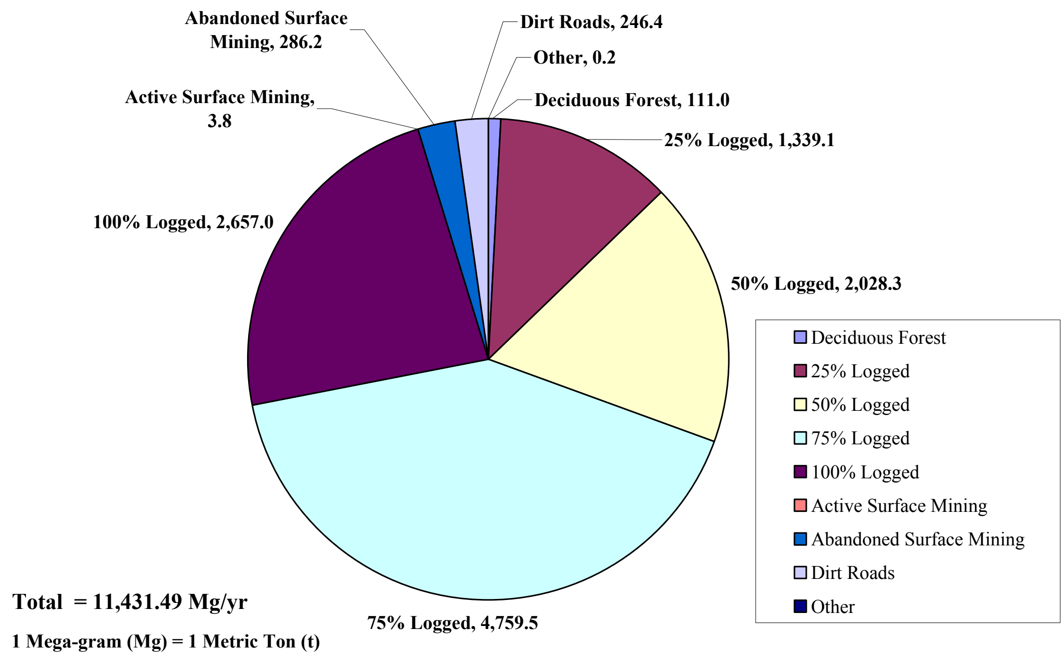


Figure 67: Smokey Creek average annual sediment yield (Mg/yr). (2006)

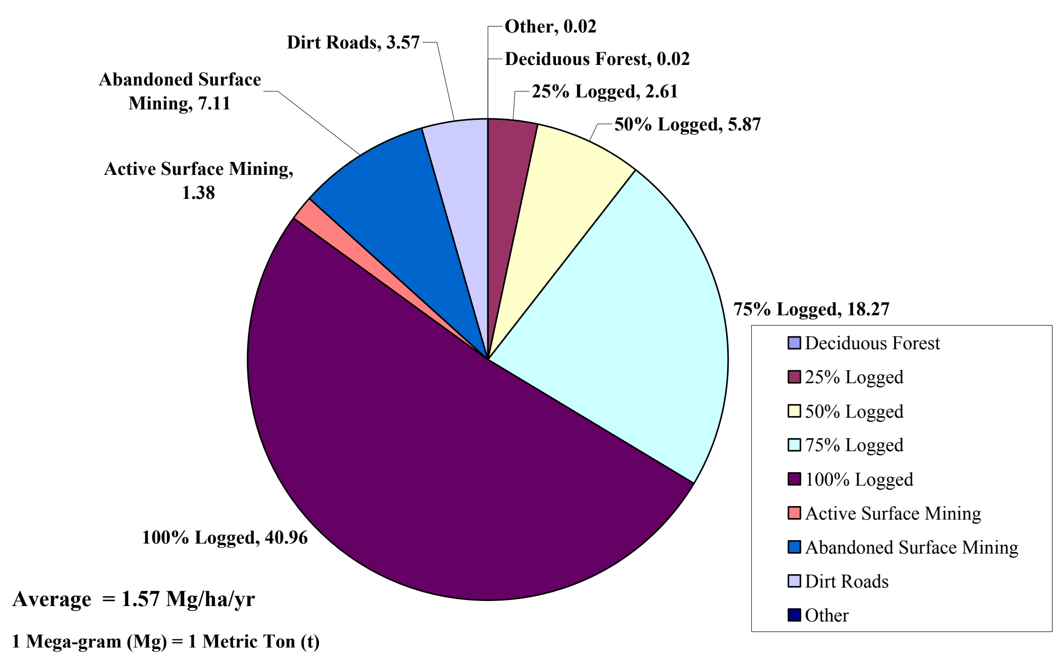


Figure 68: Smokey Creek normalized average annual sediment yield (Mg/ha/yr). (2006)

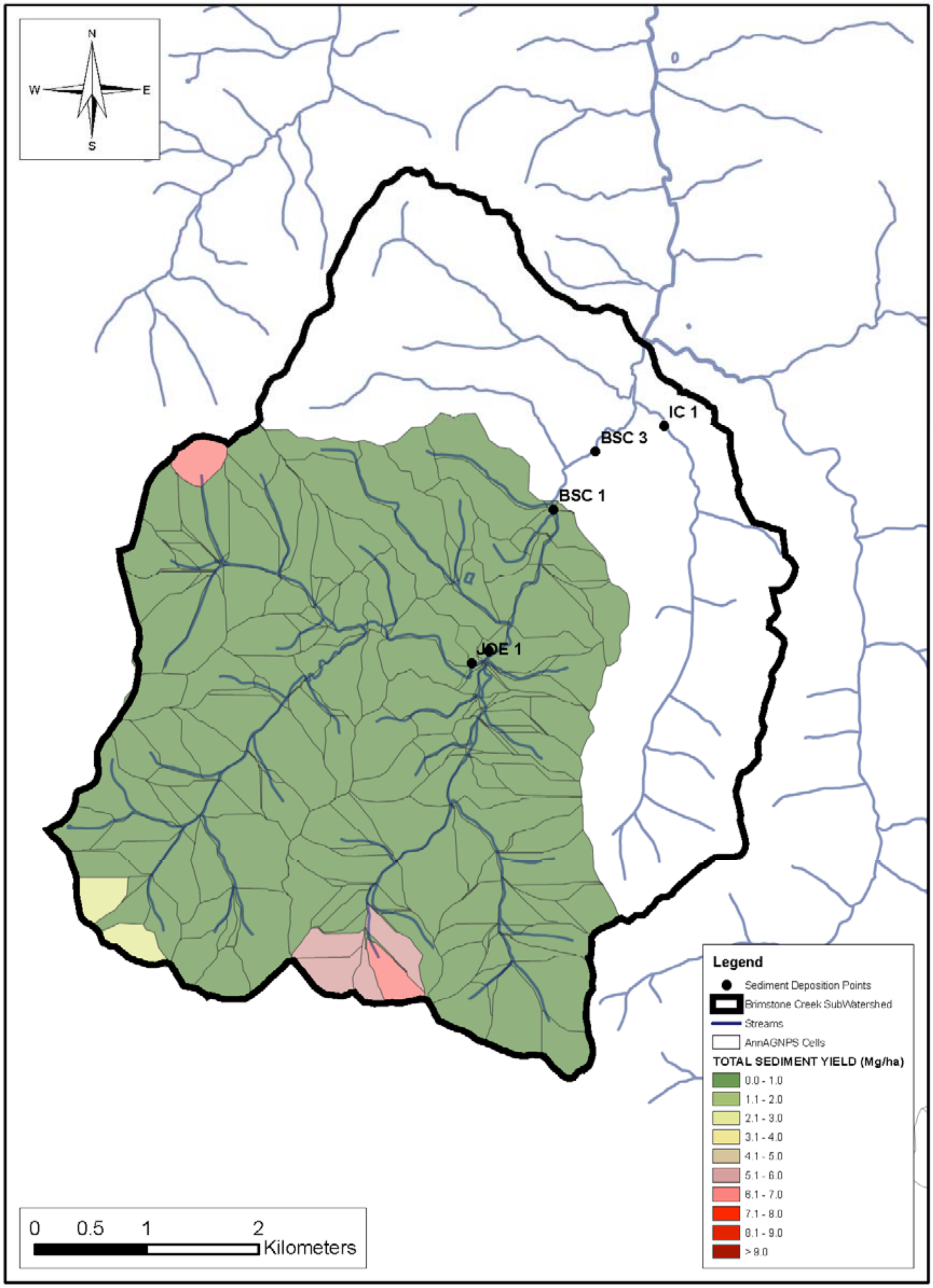


Figure 69: Brimstone Creek average annual sediment yield plot. (2006)

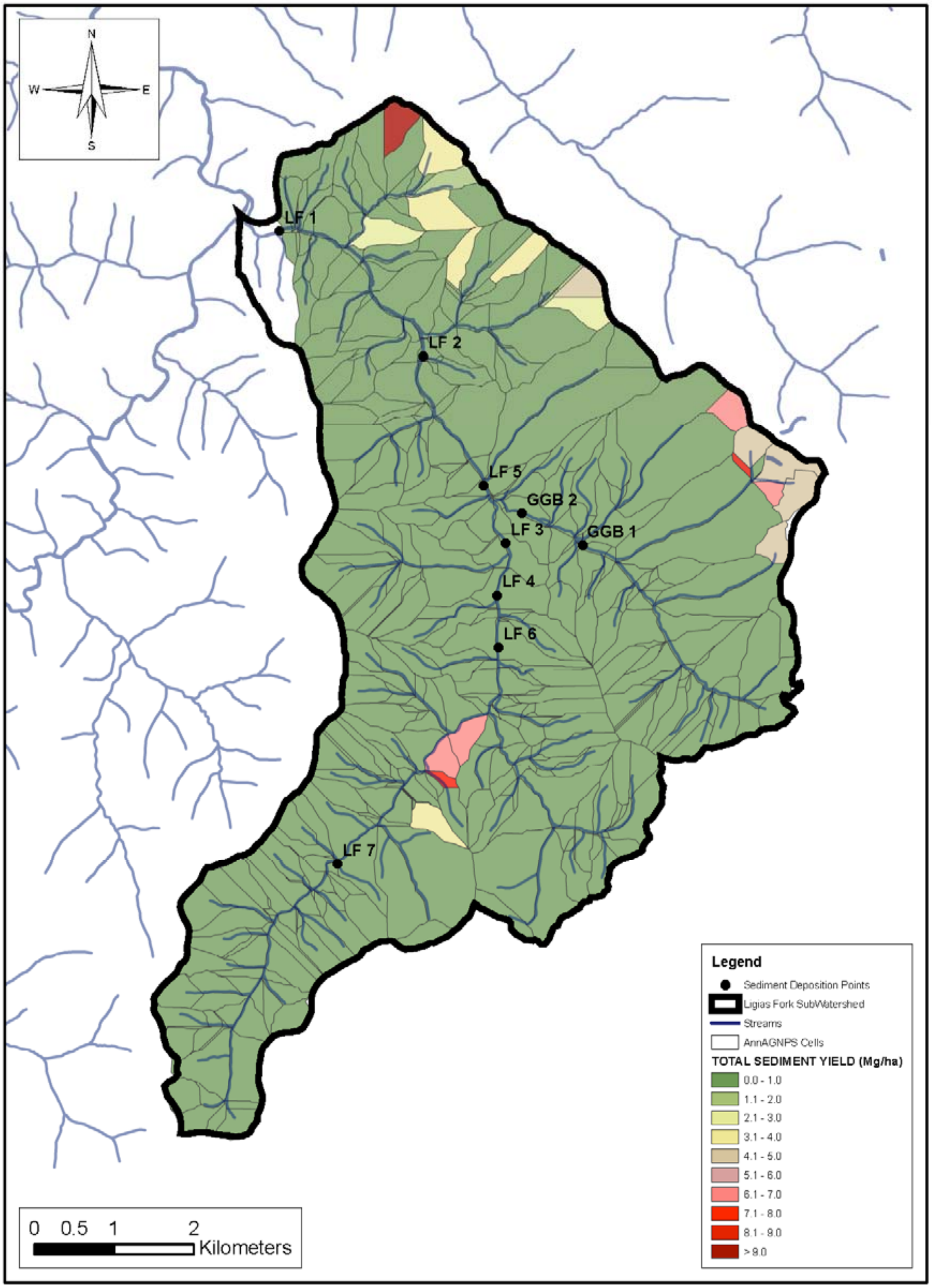


Figure 70: Ligias Fork average annual sediment yield plot. (2006)

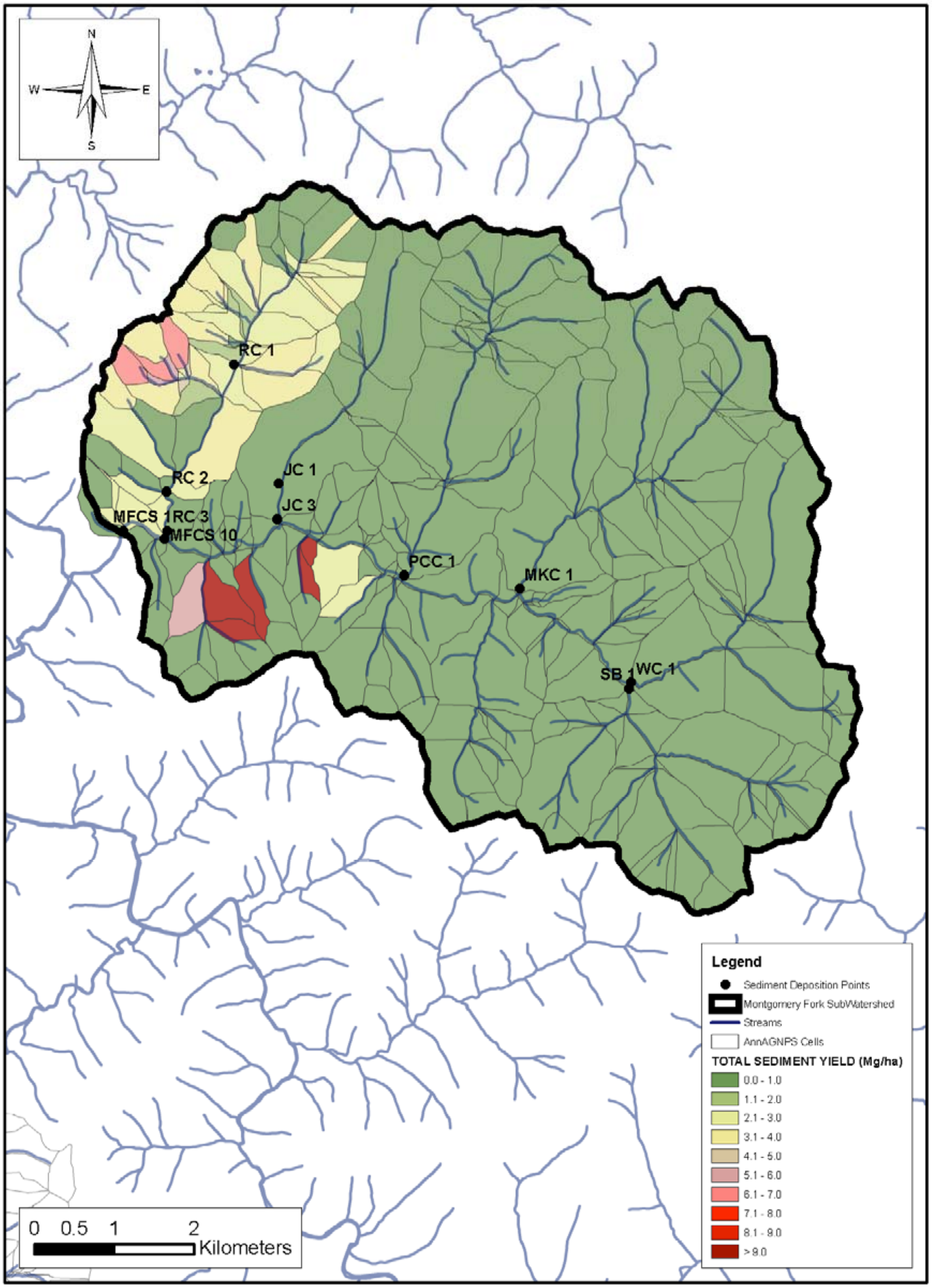


Figure 71: Montgomery Fork average annual sediment yield plot. (2006)

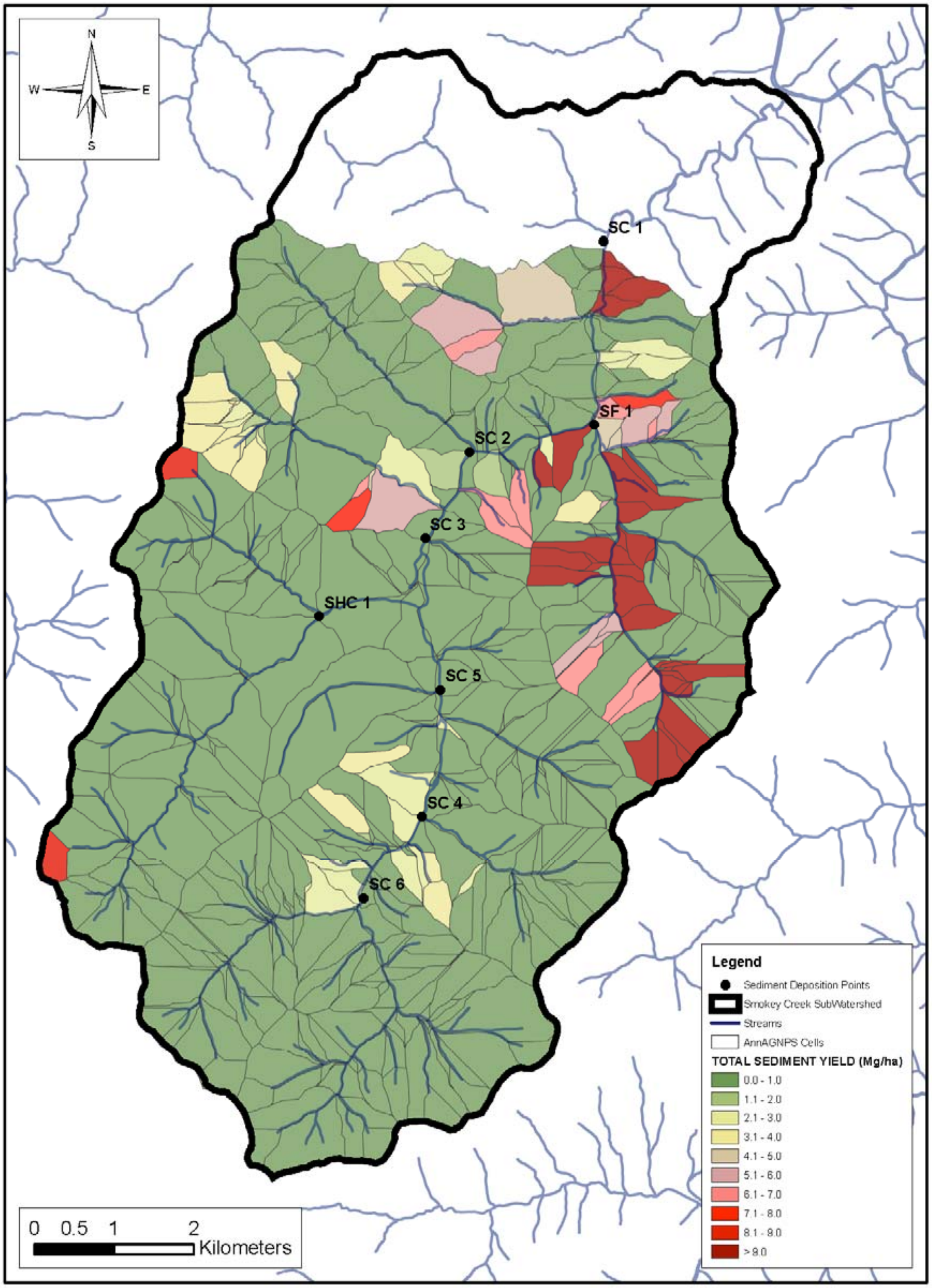


Figure 72: Smokey Creek average annual sediment yield plot. (2006)

From the AnnAGNPS pollutant loading model, the Brimstone Creek sub-watershed (which is taken as the reference watershed) produced a small amount of sediment yield within each cell due to its abundance of forests. The largest source of excessive sediment yield in the Brimstone Creek sub-watershed comes from abandoned surface mines on the steep outer portions of the watershed. It must also be shown that flow cells identified with a land use of 50% logged or greater produced a large sediment yield.

The Ligias Fork sub-watershed's greatest amount of sediment yield, estimated by the AnnAGNPS model, comes from abandoned mines left open earthed on the steep, outer edges of the watershed. Ligias Fork is also a victim of excessive sediment yield, with areas that contain logging and dirt road networks. The Ligias Fork sub-watershed contains the most abandoned mining and the least amount of logged areas (except for the reference sub-watershed), so its disturbance due to mining or logging is limited. The Ligias Fork sub-watershed contains the largest area of dirt roads, which is a major source of its sediment budget. Overall, the Ligias Fork sub-watershed seems to have the least amount of excessive sediment yield from land use disturbances when compared with the next two disturbed sub-watersheds of study.

Reviewing the AnnAGNPS model's annual average sediment yield values for Montgomery Fork sub-watershed, the flow cells with various percentages of logging are the predominate sources of excessive sedimentation into the streams. Montgomery Fork contains a large amount of 25% logged areas, which produces a large amount of sediment yield into the streams, but when normalized by area, the 50% and 75% logged areas are much more harmful sources of sedimentation. Aside from the logging activities in Montgomery Fork that seem to produce a large amount of sediment yield, the dirt roads found within this sub-watershed also show to be a large source of pollution.

Finally, the Smokey Creek sub-watershed is predicted by the AnnAGNPS pollutant loading model to have excessive sedimentation due to areas that contain more than 25% of logging and cells that have a large amount of dirt roads.. Like that of Montgomery Fork, the logging activities and dirt roads seem to be the major causes of disproportionate sediment yield into the streams.

For all four sub-watersheds analyzed in the New River Basin, any area that contained more than 25% of its area removed by forest logging produced severe sediment yield to the nearby streams. Cassie et al. (2002) observed that severely logged areas (more than 20% of the area of a watershed left deforested) showed an increase in peak flow rates due to a loss of evapotranspiration, and infiltration with the removal of trees and increasing the soils permeability by the movement of large logging equipment. From Cassie's observations, the areas where more than 20% of the landscape was logged would create more runoff, which would also increase the sediment yield.

After calibrating the AnnAGNPS pollutant loading model to provide an average annual sediment yield for 2006 and 2007, an interesting relationship was established between the percent of clays, silts, sands, and gravels in 33 different channel bed sediment depositional points in each of the four sub-watersheds in the New River Basin. Using stepwise regression analysis, the average annual weights of clay, silt, and combined clay and silt, in addition to the annual average total sediment yield produced by the AnnAGNPS model for the year 2006 (which was a year prior to the collection of the sediment in channel deposition points), were found to have a significant relationship with a combination of different deposited sediment particle characteristics measured in 2007. This relationship shows that the sediment found in stream deposit points possibly contains a historical value of the average annual hillslope sediment yield. This relationship can be useful to help watershed management determine long term geomorphic changes in a watershed. As seen with the multivariate analysis, single average annual sediment yield properties do not show a significant relationship with a single variable of the stream bed's sediment deposits for all sites in this analysis, but a combination of different sediment deposit variables do create a significant relationship with average annual sediment yield values. Therefore, more stream bed sediment data analyzed through other statistical investigations may better define the existence of a relationship and correlation between the two sets of data.

As more stream bed sediment data could strengthen the relationship between stream sediment deposits and hillslope sediment yield, there are a few other features in this study that could produce some error in the resultant findings. First, the AnnAGNPS pollutant loading model is just a prediction tool that provides an estimate of the amount of average annual sediment yield occurring on a hillslope due a variety of land use activities, soil types, weather patterns, and terrain. Much caution must be given when relying on a computer program to assess hydrological and sedimentlogical processes occurring over time, but this tool is currently a good approach to assess the natural movement of water and sediment within a large watershed. The values used for model calibration based on land use activities have a large amount of variability, but were carefully adjusted to resemble values commonly found in most texts. Overall, the AnnAGNPS pollutant loading model was used in an professional and scientific manner to determine if a relationship exists between the stream bed sediment deposits and the hillslope sediment yield within the Cumberland Plateau region of Tennessee. In trusting the calibrated pollutant loading model's results of average annual hillslope sediment yield, this study indicates that a relationship exists, but could be better explained with more investigations on this subject.

5.2 Suggestions

For general watershed management of different activities and the changes in runoff and sediment yield that occur by alterations of the landscape, the AnnAGNPS pollutant model has the potential to be used successfully in a mountainous region that contains various land uses other than agriculture. This model will need to be calibrated to actually define the different variables used to predict runoff (i.e., curve numbers, Manning's n, etc.) and sediment yield (RUSLE C and P factors) if common textbook values are not adequately defined for certain land uses and soils, but it should produce satisfactory results in a difficult environment like the New River Basin. This model uses measured characteristics of the area simulated, which can be an exhaustive process to collect and program into its database. The program also lacks the ability to adjust the sizes of specific cell grids of interest. For instance, the user will define a minimum flow length and cell size for the entire watershed, but many times several of the flow cells that have steep slopes or unique terrain definitions will be created with such a small area or flow length that it causes the model to have a series of errors in producing different calculations. Therefore, the cell size is set by a single set of values and will fluctuate uniformly, which produces a wide range of different cell sizes that may not properly define the dominant soils and land use activities in a watershed.

Another difficult problem experienced with the AnnAGNPS pollutant model was with the incorporation of dirt roads. There are several options for direct point sources of various agricultural pollutants, but there is no option for sediment point sources in the program, which could be used for smaller disturbances that would provide a large amount of sediment into the streams but would not be picked up by the flow cells. With many agricultural facilities, dirt roads are a common feature (or at least in Tennessee) and with the many studies that have shown dirt roads being a large cause of sediment yield to streams, one would think that the AnnAGNPS pollutant loading model would include a feature to define these sources of runoff and sediment yield.

For the mountainous terrain of the New River, the lack of precipitation data definitely limited the accuracy of the AnnAGNPS pollutant model. When using this model as a tool for long term watershed management, it is highly suggested to adequately prepare several locations to monitor the weather. For everything associated with the AnnAGNPS model, the better the data input, the better the results.

In conclusion, the appropriate use of the AnnAGNPS pollutant loading model in non-agricultural, mountainous watershed has the possibilities to be a useful tool with management of TMDL to the nearby streams. This computer model can currently be used to analyze the severity of multiple pollution sources, but needs improvement to make it user friendly as well as creating better techniques to accurately and consistently produce actual storm water runoff and sediment yield values. For instance, the model should replace the daily precipitation amount required with an hourly precipitation requirement to better represent the intensity of rainfall and to remove the NRCS TR-55 precipitation distribution type for a general location of the U.S. Overall, the AnnAGNPS pollutant loading model has promise to be a good watershed management tool for applications other than agriculture, but currently contains a few problems that need to be resolved.

Finally, looking at the overall comparison of the hillslope sediment yield with that of the sediment depositional points, the relationships could be better defined and represented with additional measurements taken throughout the watersheds. Many errors could have developed from the measuring of the sediment particle size distributions as well as the collection of the sediment in the channel. From a bivariate statistical analysis, the JMP software noted four of the 33 sites contained possible outliers. No outliers were defined in the statistical analysis because there was a limited amount of data and the author attempted to take great care in collecting and analyzing the sediment samples. Looking closely at the stepwise regression analysis plots, there is a data point found in the four significant sediment yield relationships that creates a leverage affect with the statistical results. With more measured sediment from stream bed depositional points, a better analysis could be established to confirm outliers or provide a greater distribution of different types of soil particles. There was a great amount of variability with all the stream bed sediment samples, which is expected in the study of sediment transport. As I have stated continuously through the project to others who have taken some interest in this study, the study of sediment is a chaotic and complex process. The more sediment transport process are used to predict geomorphological changes in the watershed and streams as well as the habitat for biota with increased sedimentation in stream environments, the study of sediment transport will become less complex, chaotic, and astonishing.

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List of References

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Appendices

Appendix A

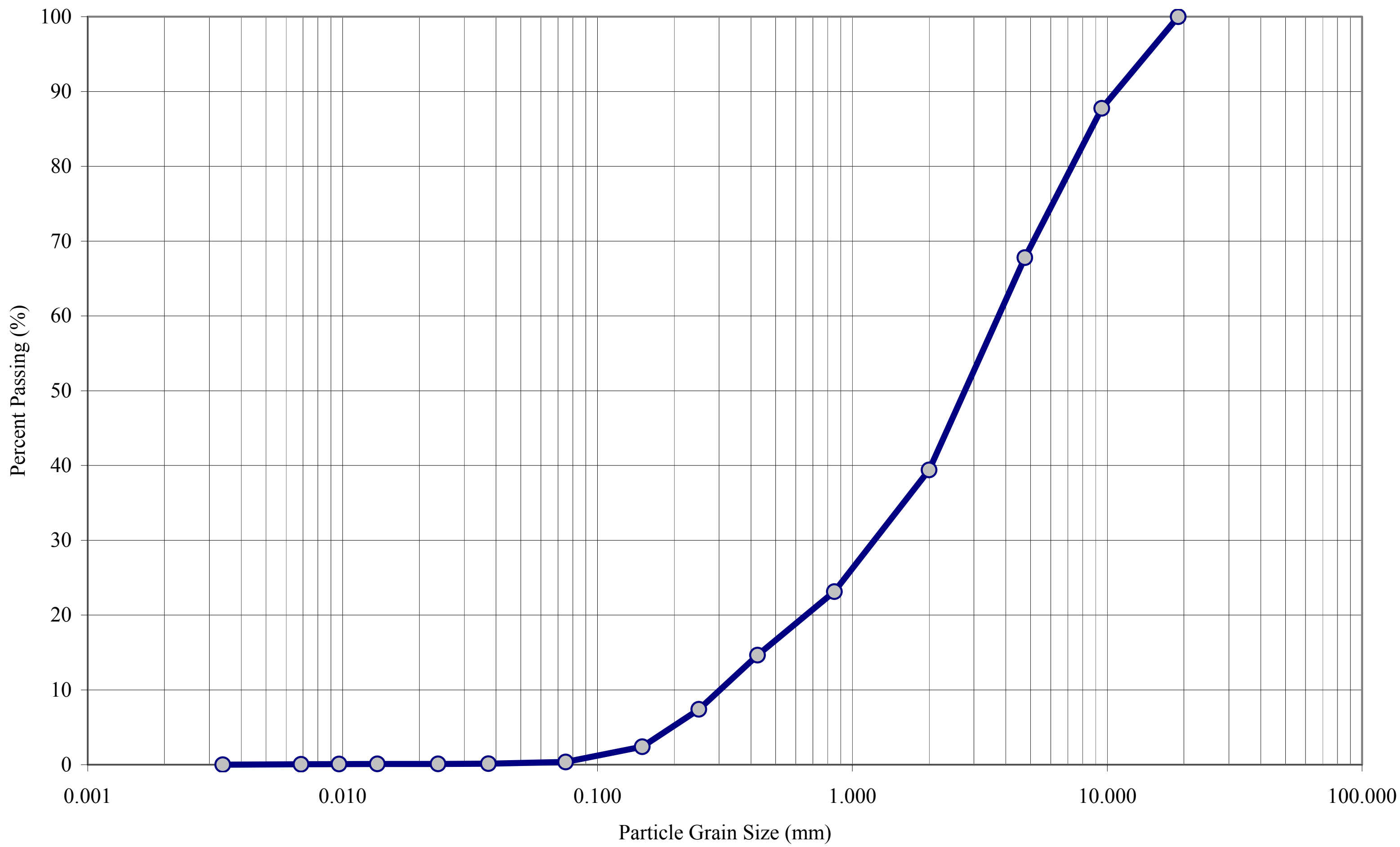
GPS Coordinates of Stream Bed Deposition Points

No.	GPS Site ID (---)	Sub-Watershed (---)	UTM COORDINATES Easting (meters)	Northing (meters)	Elevation (meters)
1	BSC 1	Brimstone Creek	724,066	4,014,829	399
2	BSC 2	Brimstone Creek	723,488	4,013,568	425
3	BSC 3	Brimstone Creek	724,437	4,015,349	381
4	IC 1	Brimstone Creek	725,053	4,015,581	404
5	JOE 1	Brimstone Creek	723,332	4,013,459	409
6	GGB 1	Ligias Fork	745,010	4,006,255	469
7	GGB 2	Ligias Fork	744,253	4,006,655	438
8	LF 1	Ligias Fork	741,210	4,010,193	408
9	LF 2	Ligias Fork	743,011	4,008,626	374
10	LF 3	Ligias Fork	744,046	4,006,282	456
11	LF 4	Ligias Fork	743,938	4,005,627	468
12	LF 5	Ligias Fork	743,772	4,007,003	436
13	LF 6	Ligias Fork	743,954	4,004,977	471
14	LF 7	Ligias Fork	741,900	4,002,280	575
15	MFCS 1	Montgomery Fork	736,370	4,023,646	367
16	MFCS 10	Montgomery Fork	736,889	4,023,545	372
17	RC 1	Montgomery Fork	737,758	4,025,733	455
18	RC 2	Montgomery Fork	736,918	4,024,137	400
19	RC 3	Montgomery Fork	736,927	4,023,644	380
20	JC 1	Montgomery Fork	738,320	4,024,237	421
21	JC 3	Montgomery Fork	738,304	4,023,789	391
22	MKC 1	Montgomery Fork	741,339	4,022,921	477
23	PCC 1	Montgomery Fork	739,890	4,023,088	394
24	SB 1	Montgomery Fork	742,711	4,021,671	483
25	WC 1	Montgomery Fork	742,741	4,021,748	476
26	SC 1	Smokey Creek	734,326	4,016,826	382
27	SC 2	Smokey Creek	732,652	4,014,181	399
28	SC 3	Smokey Creek	732,095	4,013,103	410
29	SC 4	Smokey Creek	732,053	4,009,619	449
30	SC 5	Smokey Creek	732,287	4,011,204	436
31	SC 6	Smokey Creek	731,326	4,008,590	451
32	SF 1	Smokey Creek	734,213	4,014,525	390
33	SHC 1	Smokey Creek	730,765	4,012,125	438

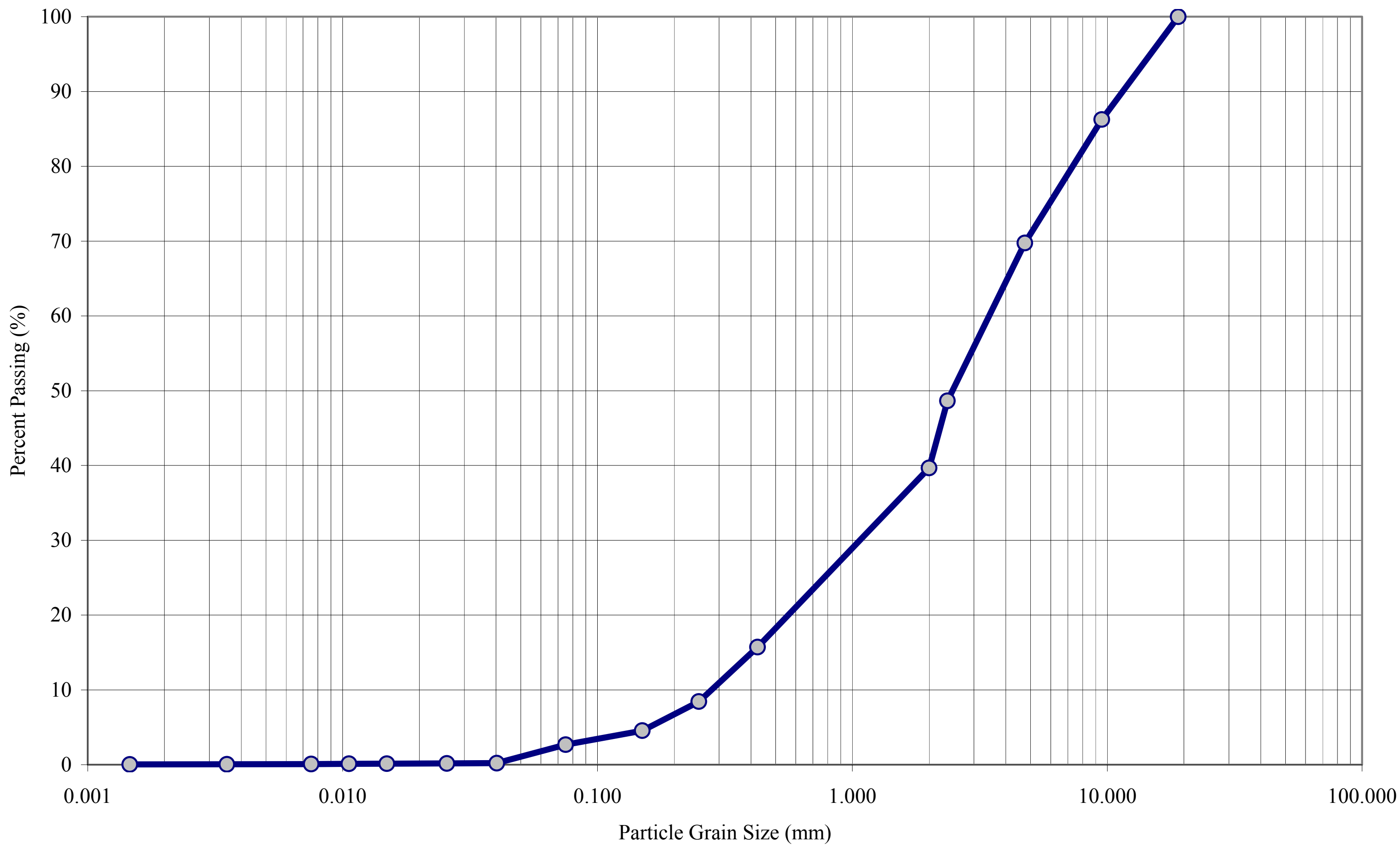
Appendix B

Particle Size Distributions for each Stream Bed Deposition Point

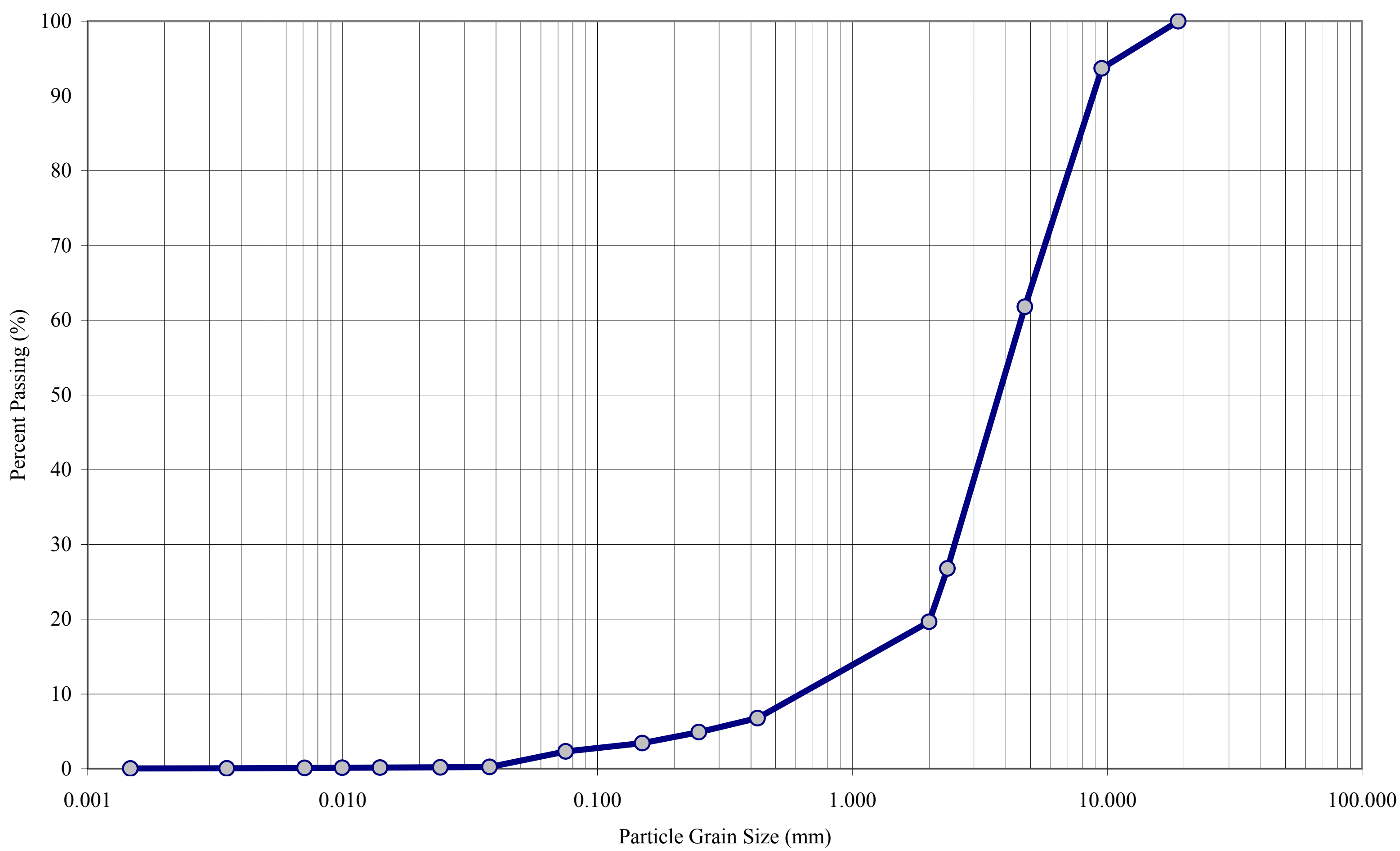
BSC-1 Particle Size Distribution

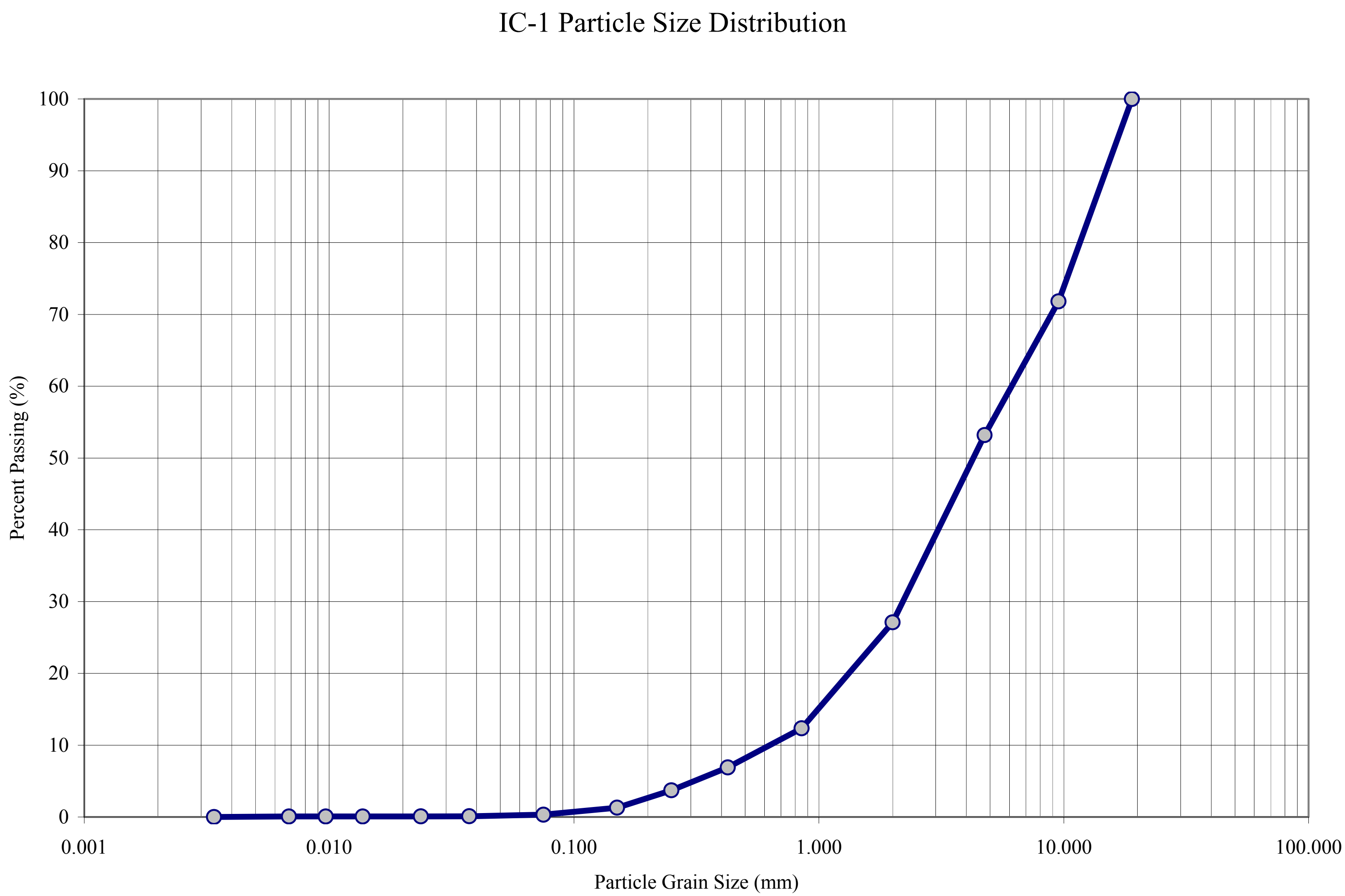


BSC-2 Particle Size Distribution

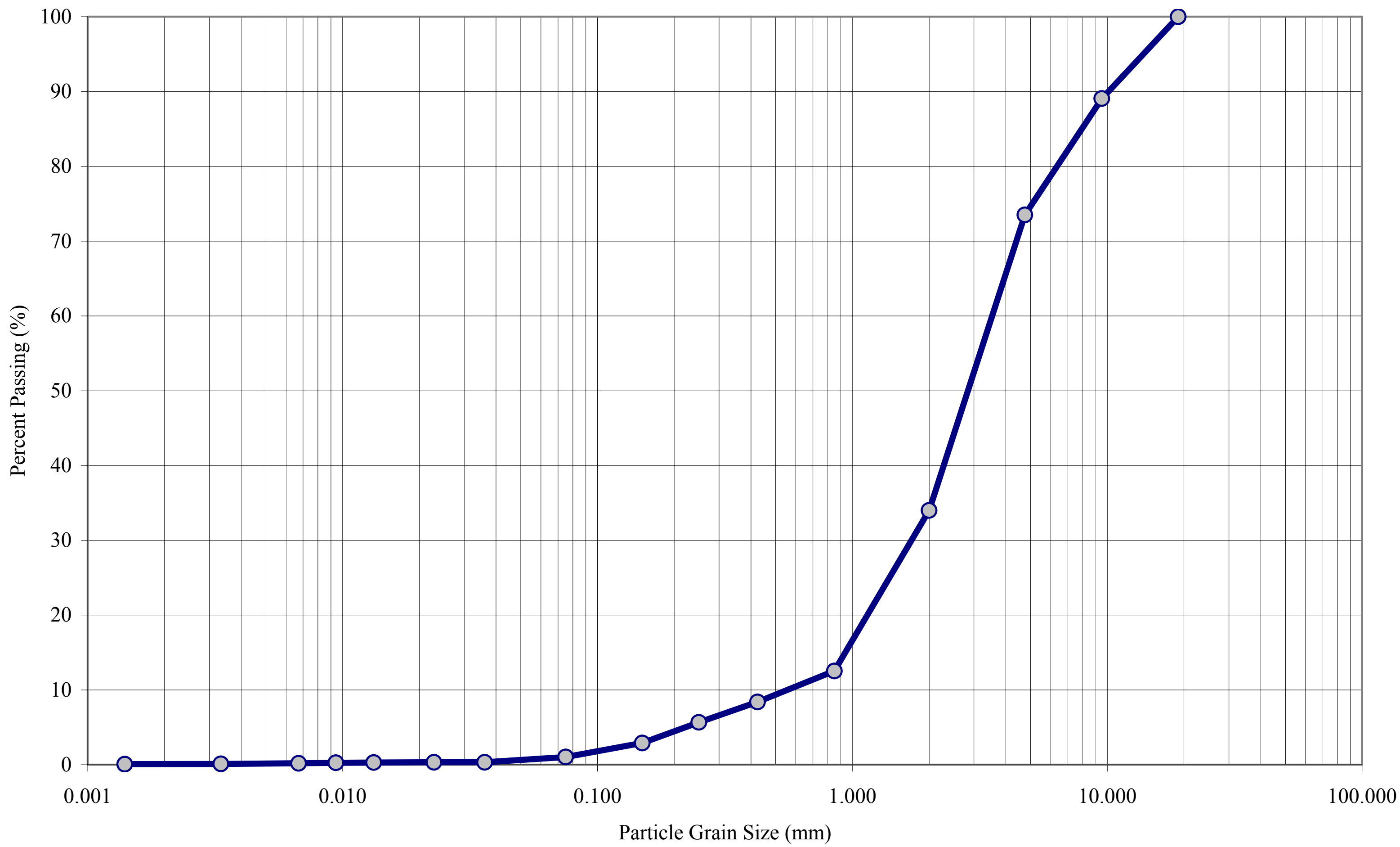


BSC-3 Particle Size Distribution

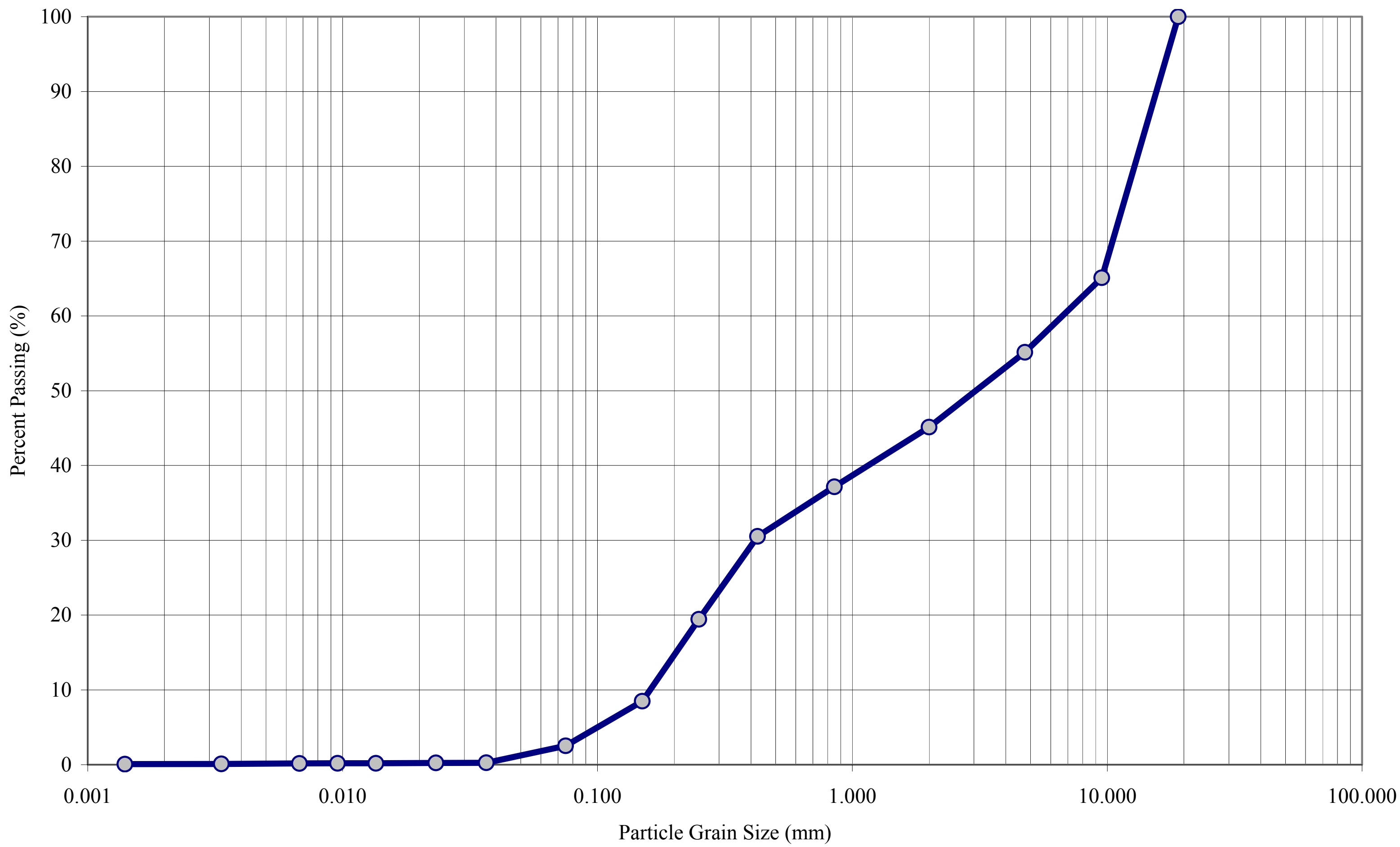



IC-1 Particle Size Distribution
Percent Passing (%)
100
90
80
70
60
50
40
30
20
10
0
0.001
0.010
0.100
1.000
10.000
100.000
Particle Grain Size (mm)

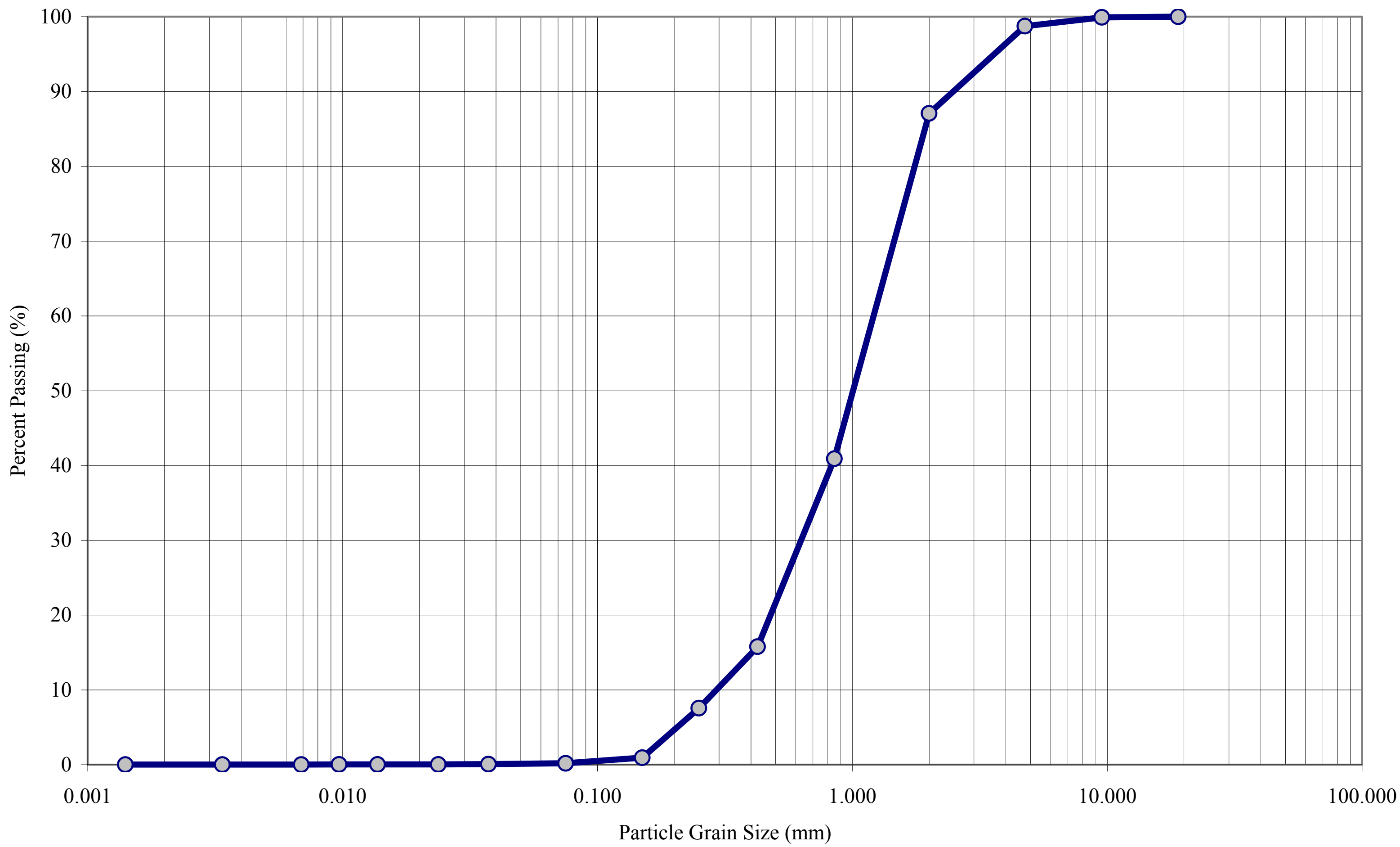
JOE-1 Particle Size Distribution



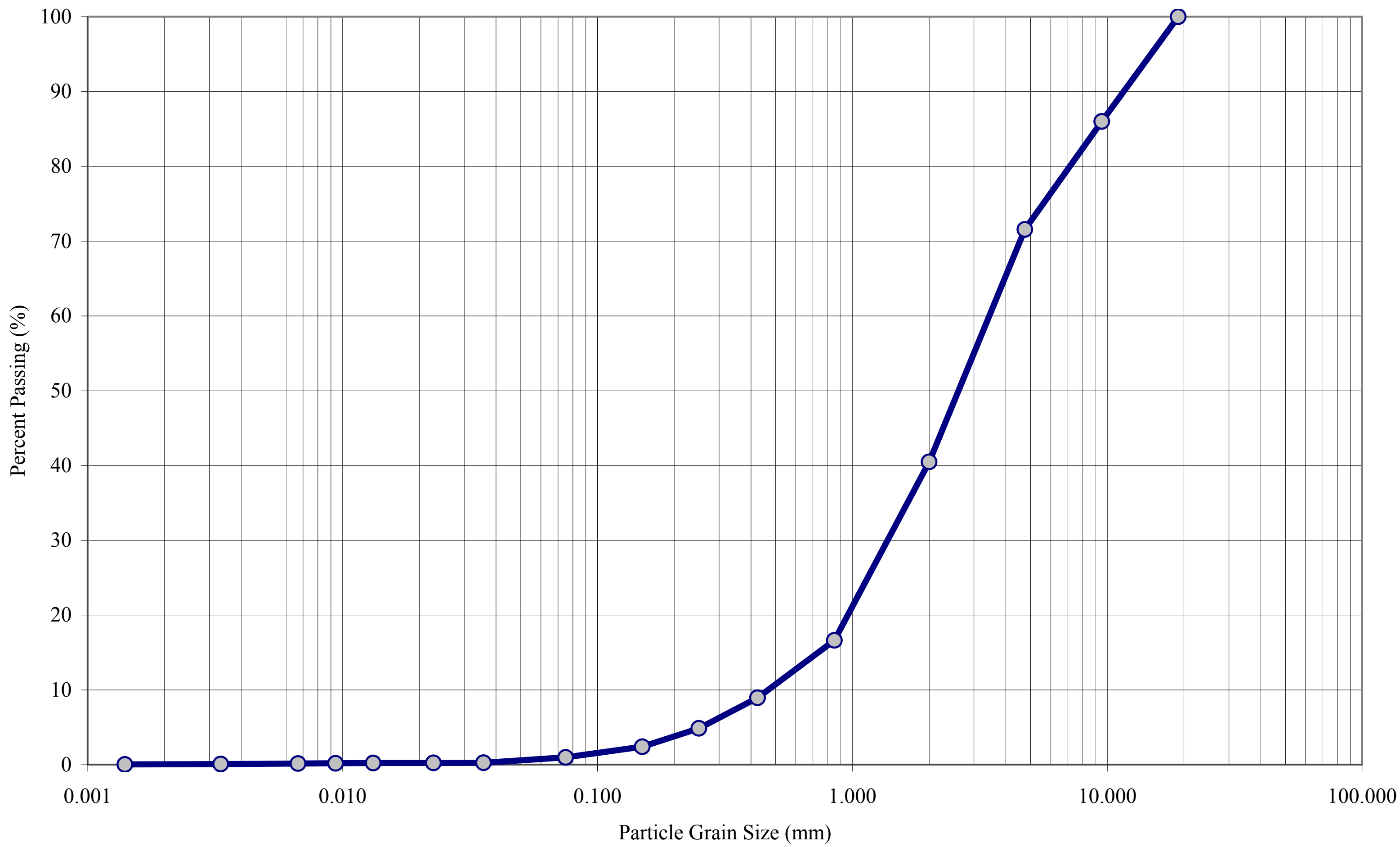
LF-1 Particle Size Distribution

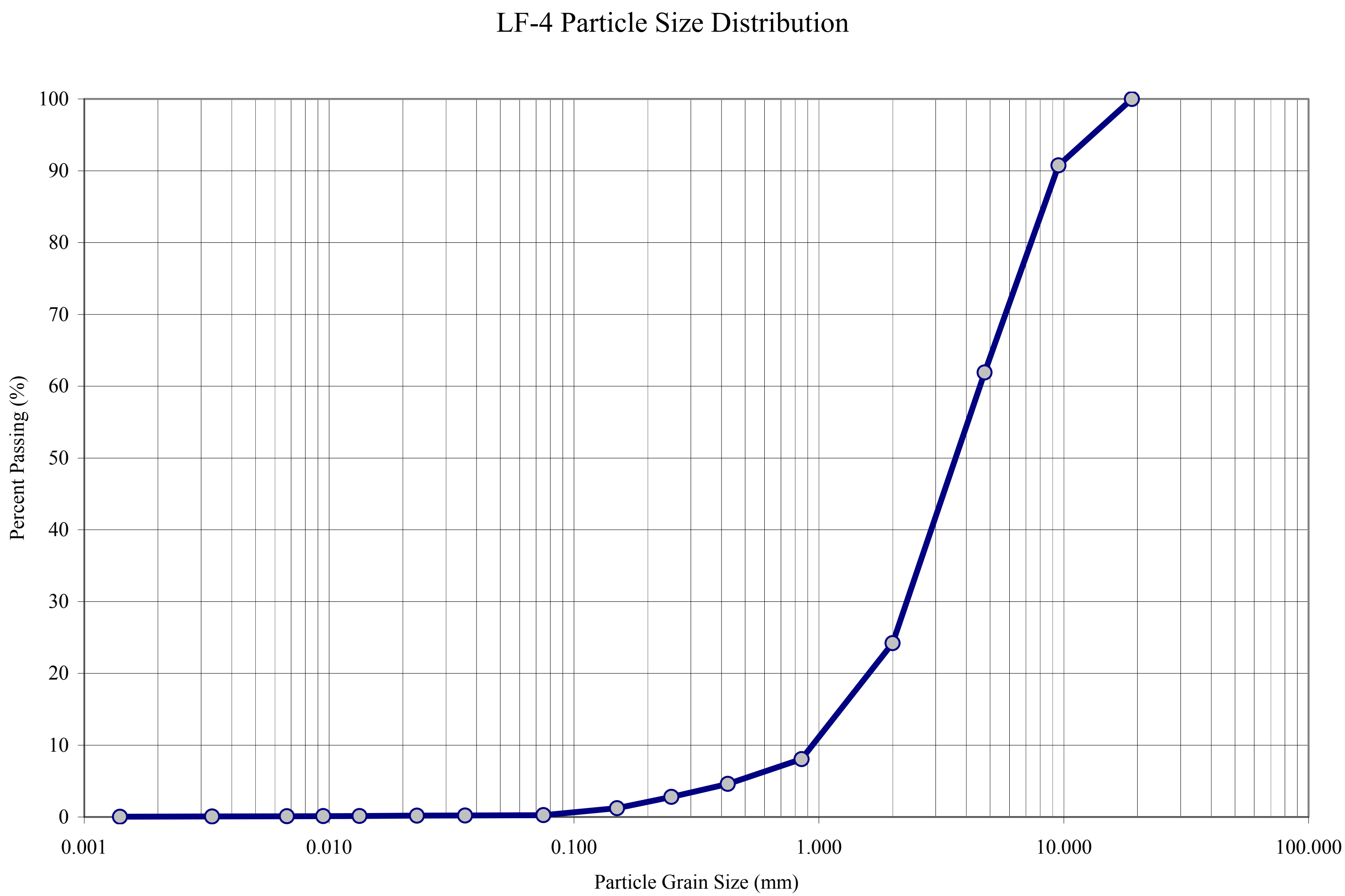


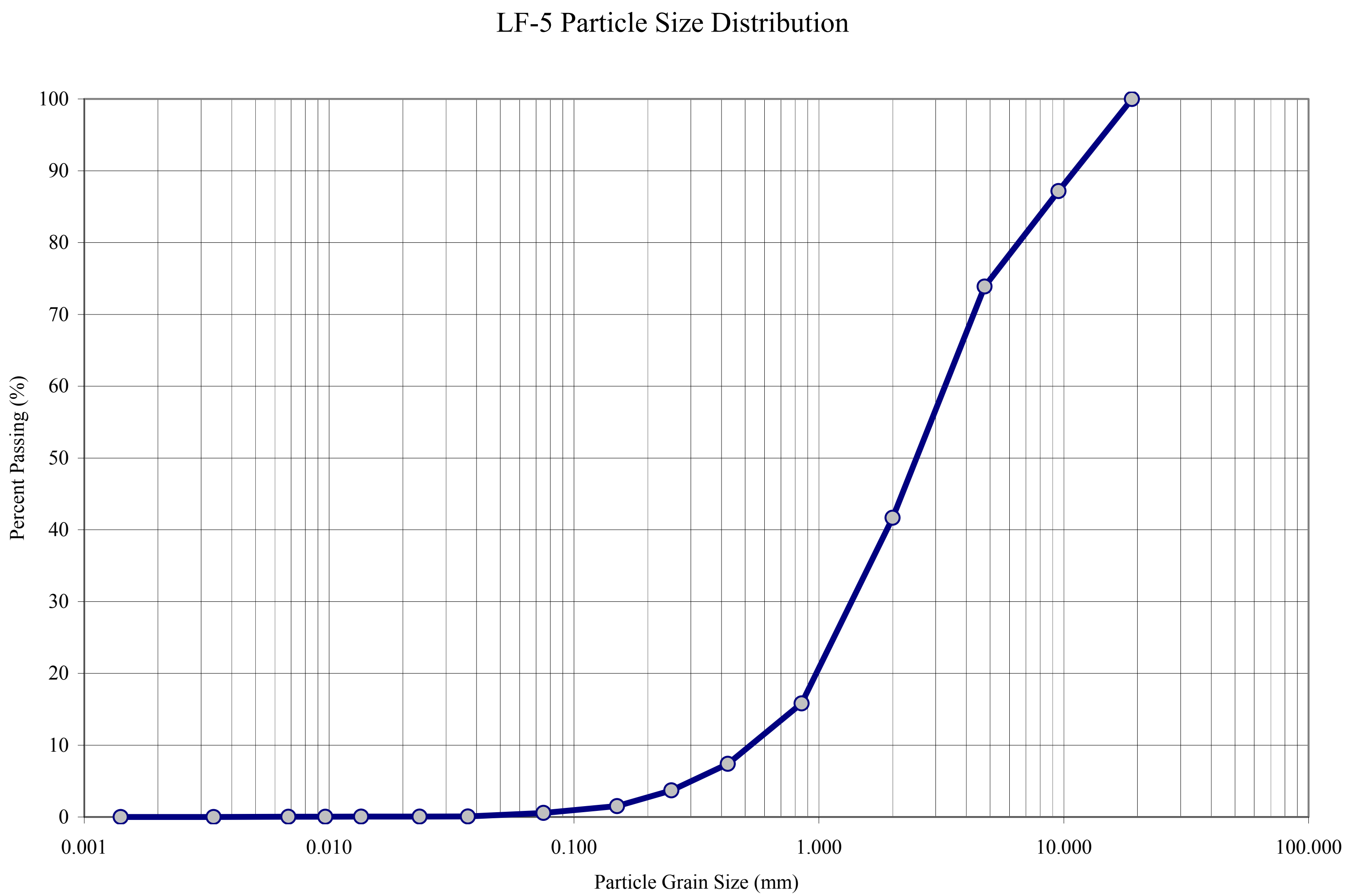
LF-2 Particle Size Distribution



LF-3 Particle Size Distribution

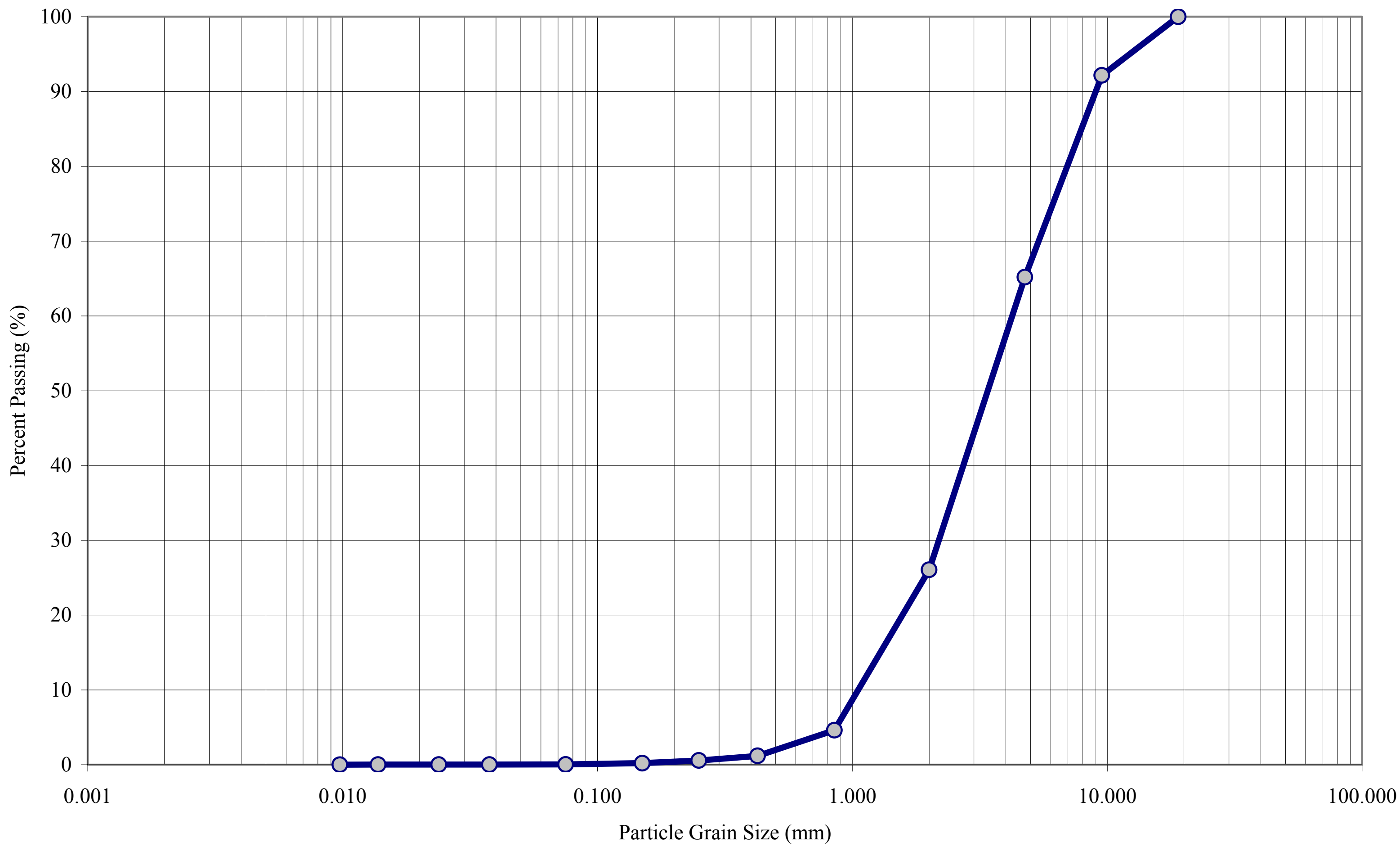



LF-4 Particle Size Distribution
Percent Passing (%)
100
90
80
70
60
50
40
30
20
10
0
0.001
0.010
0.100
1.000
10.000
100.000
Particle Grain Size (mm)

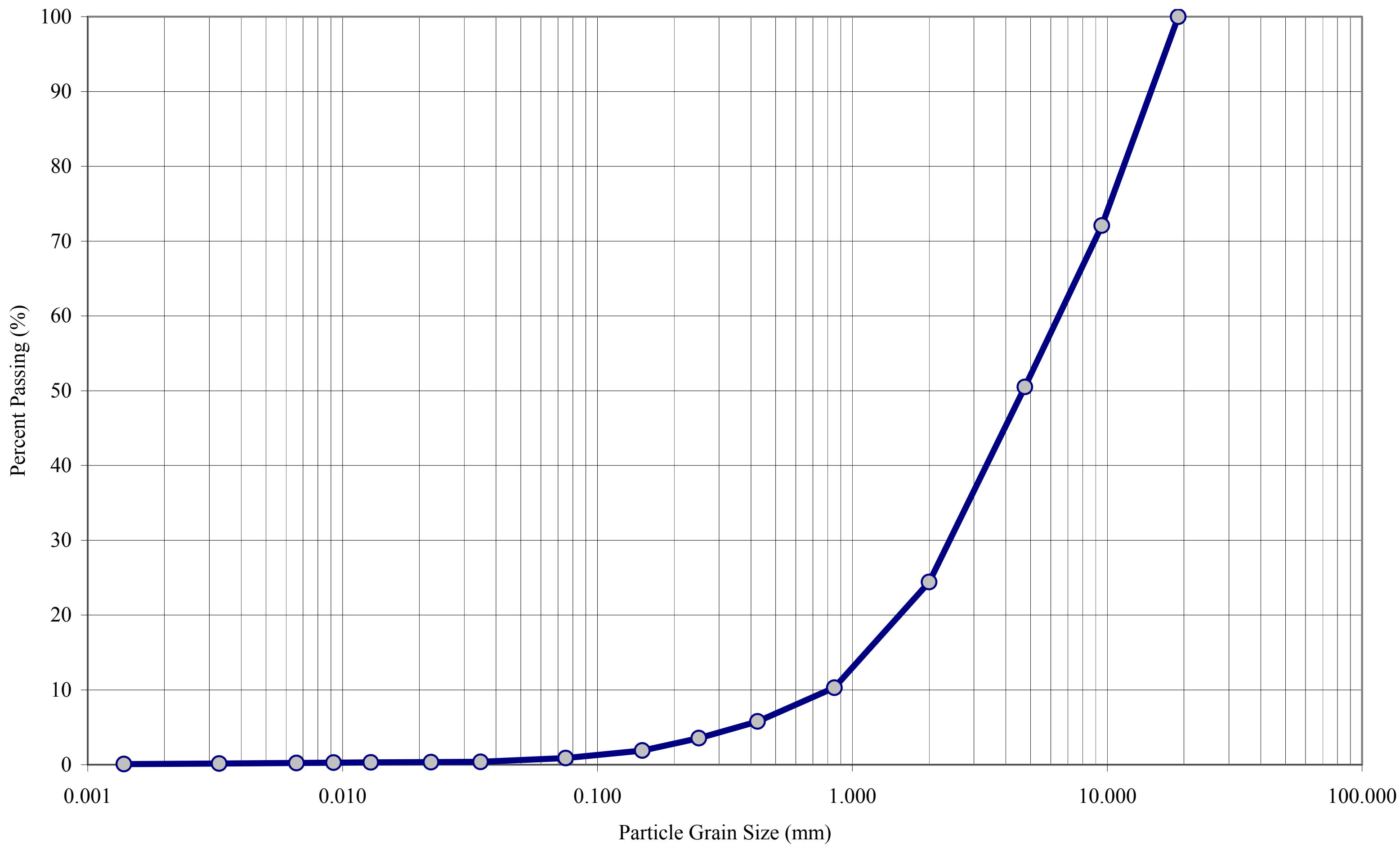


LF-5 Particle Size Distribution
Percent Passing (%)
100
90
80
70
60
50
40
30
20
10
0
0.001
0.010
0.100
1.000
10.000
100.000
Particle Grain Size (mm)

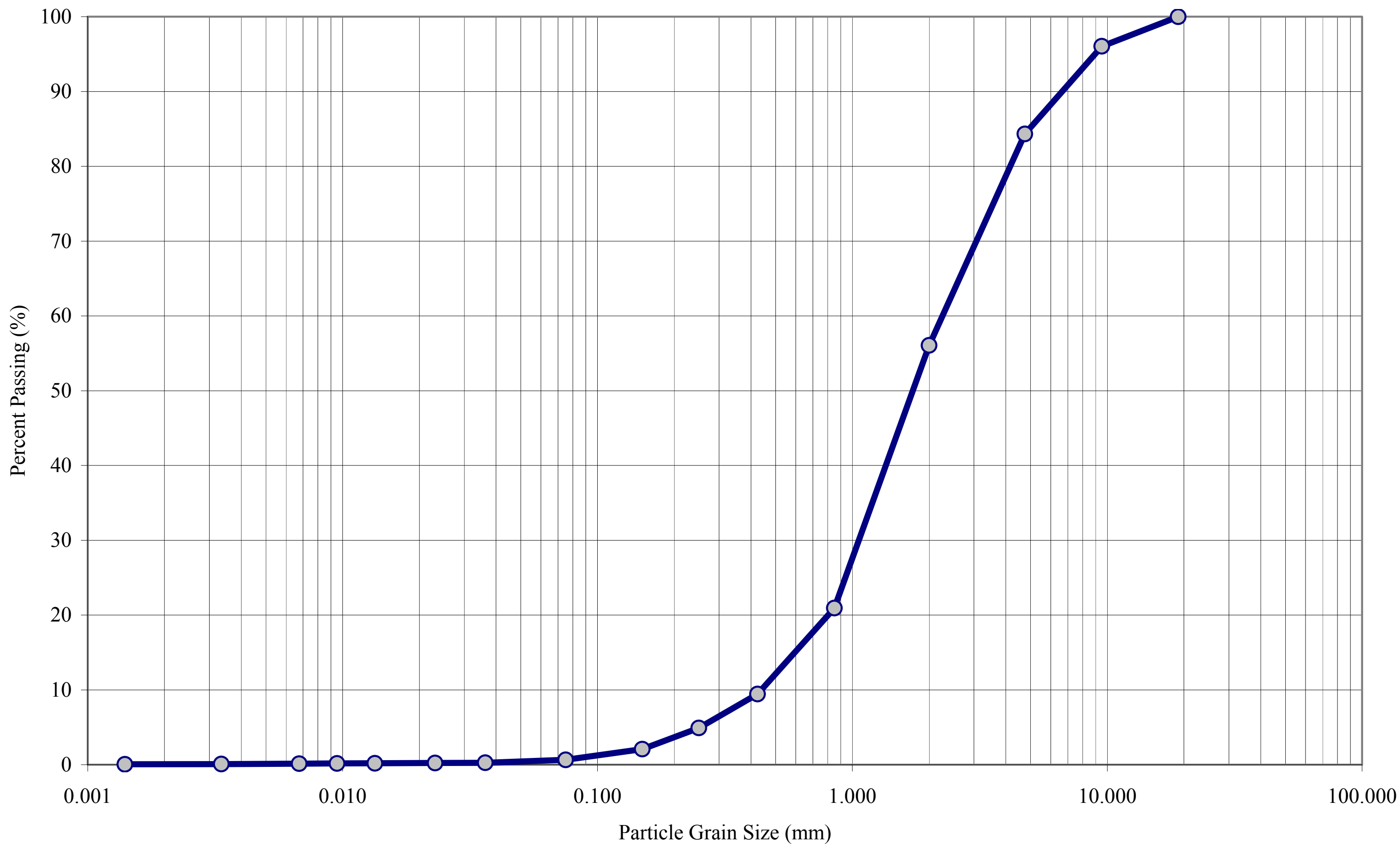
LF-6 Particle Size Distribution



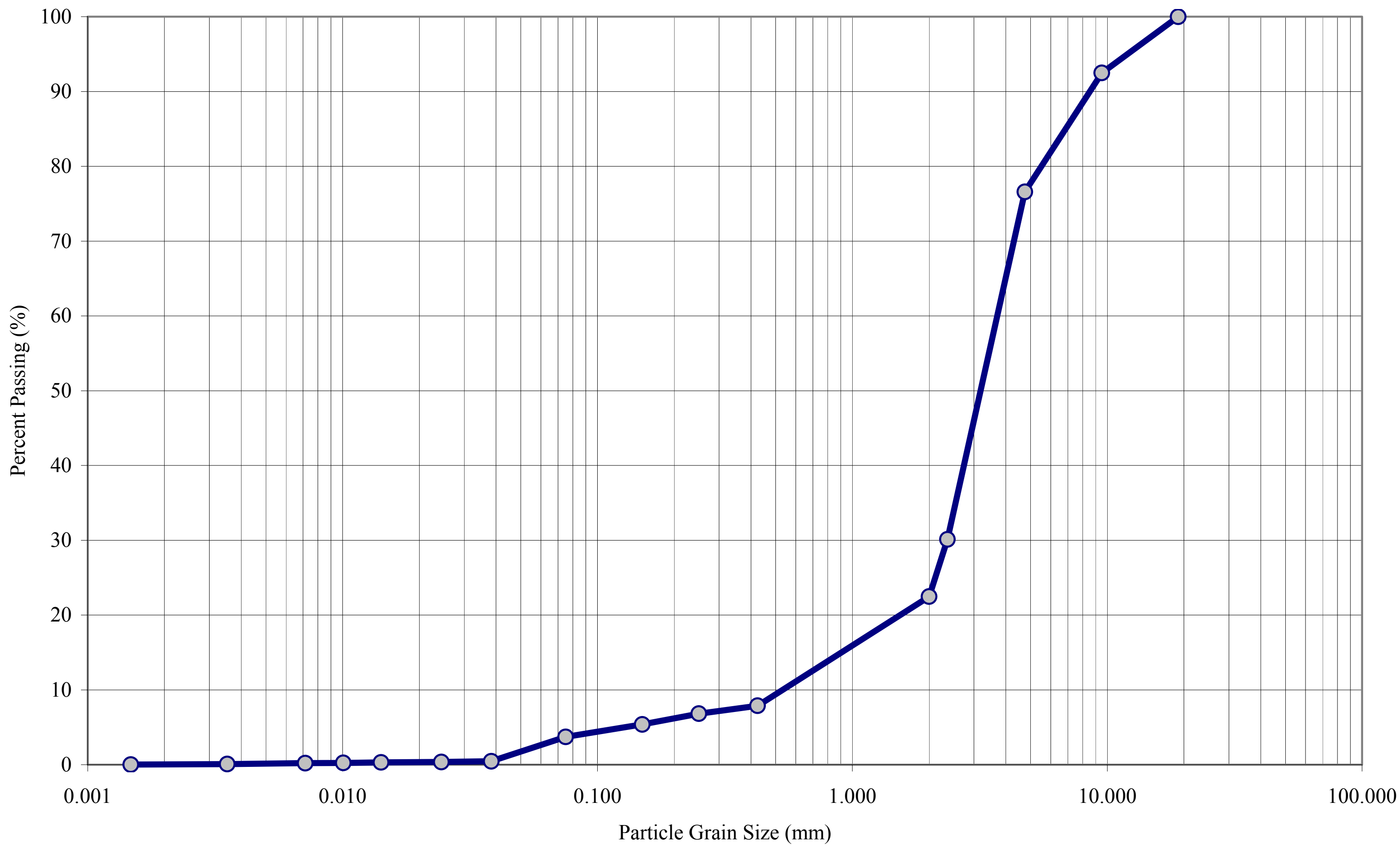
LF-7 Particle Size Distribution



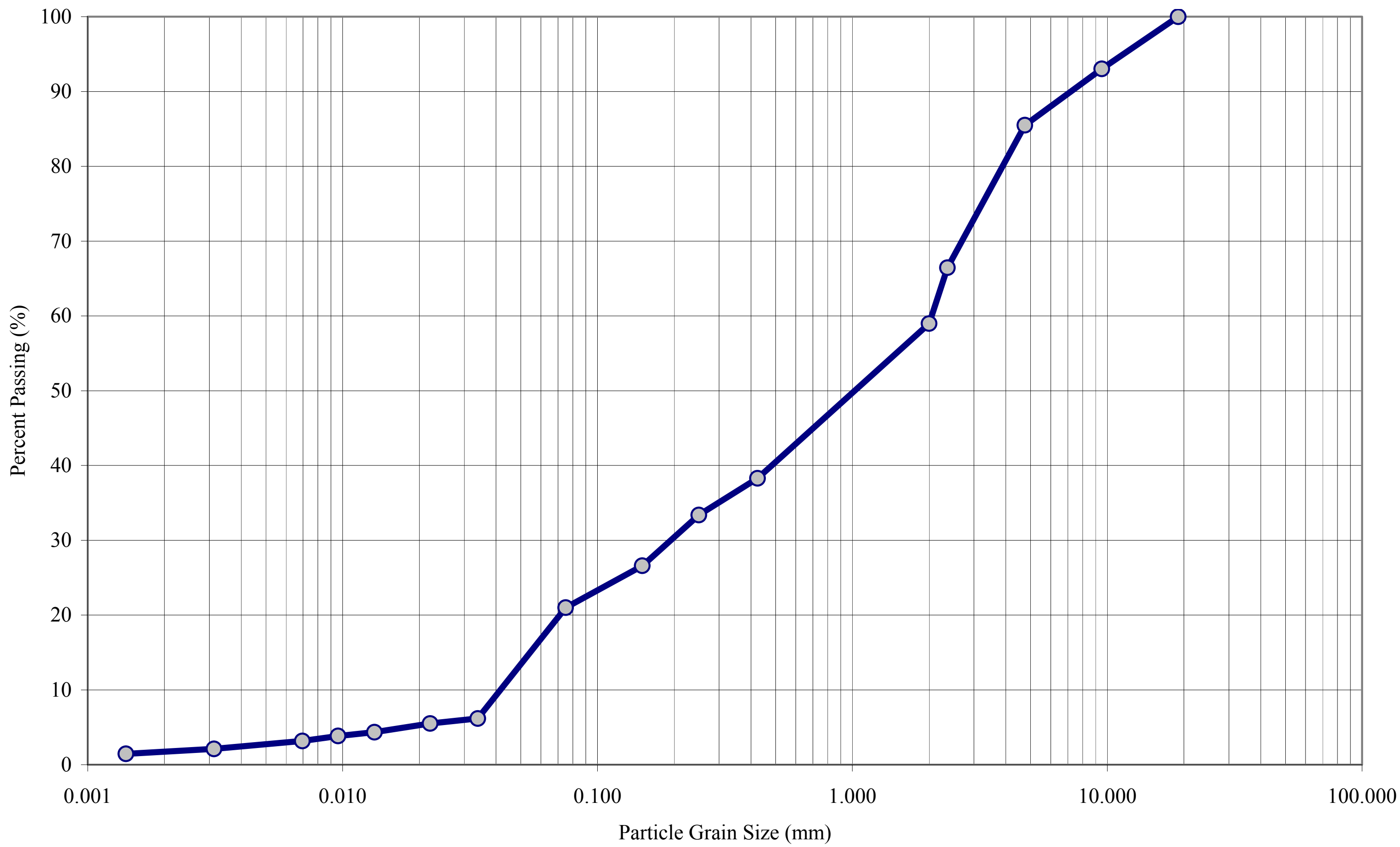
GGB-1 Particle Size Distribution



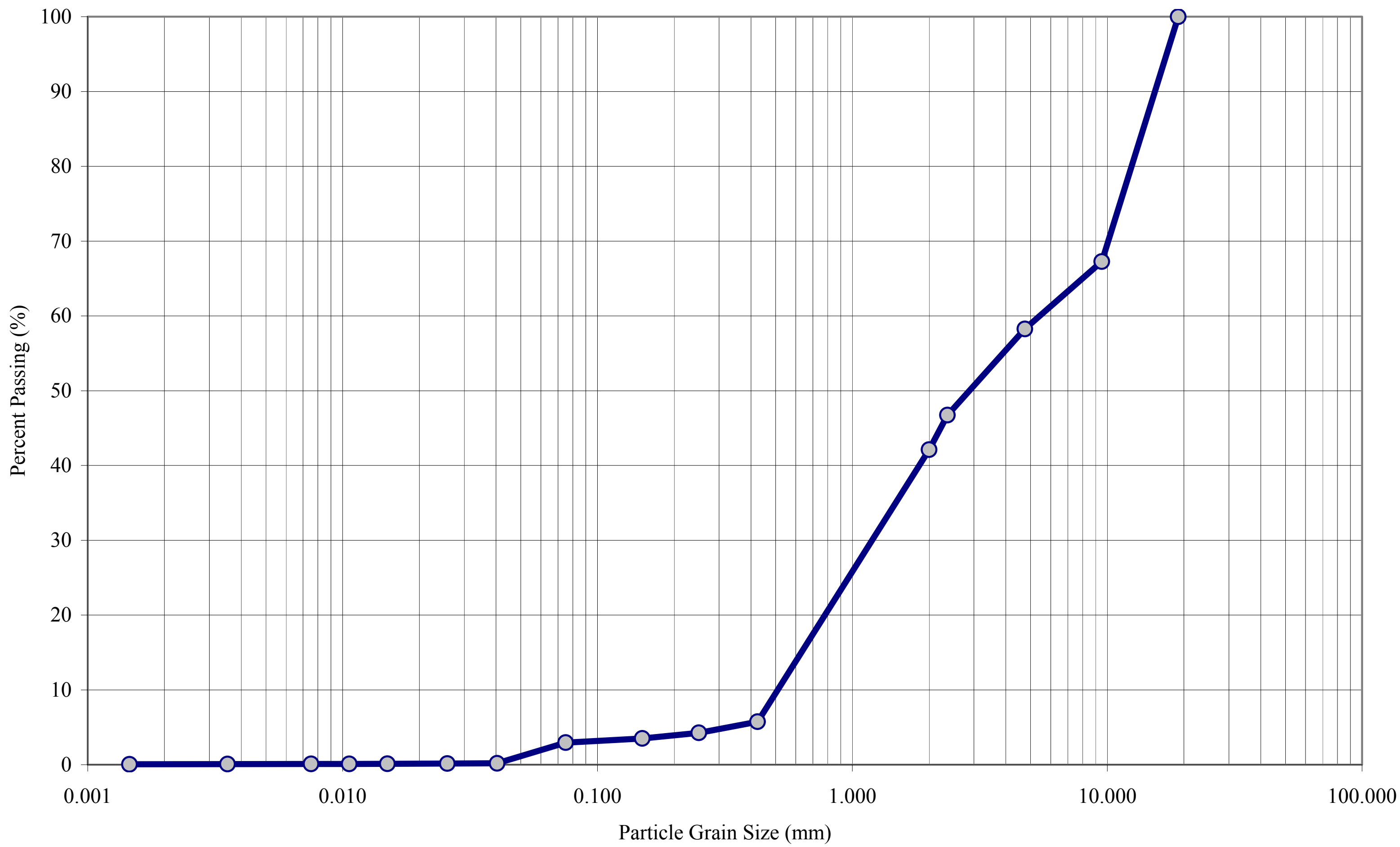
GGB-2 Particle Size Distribution



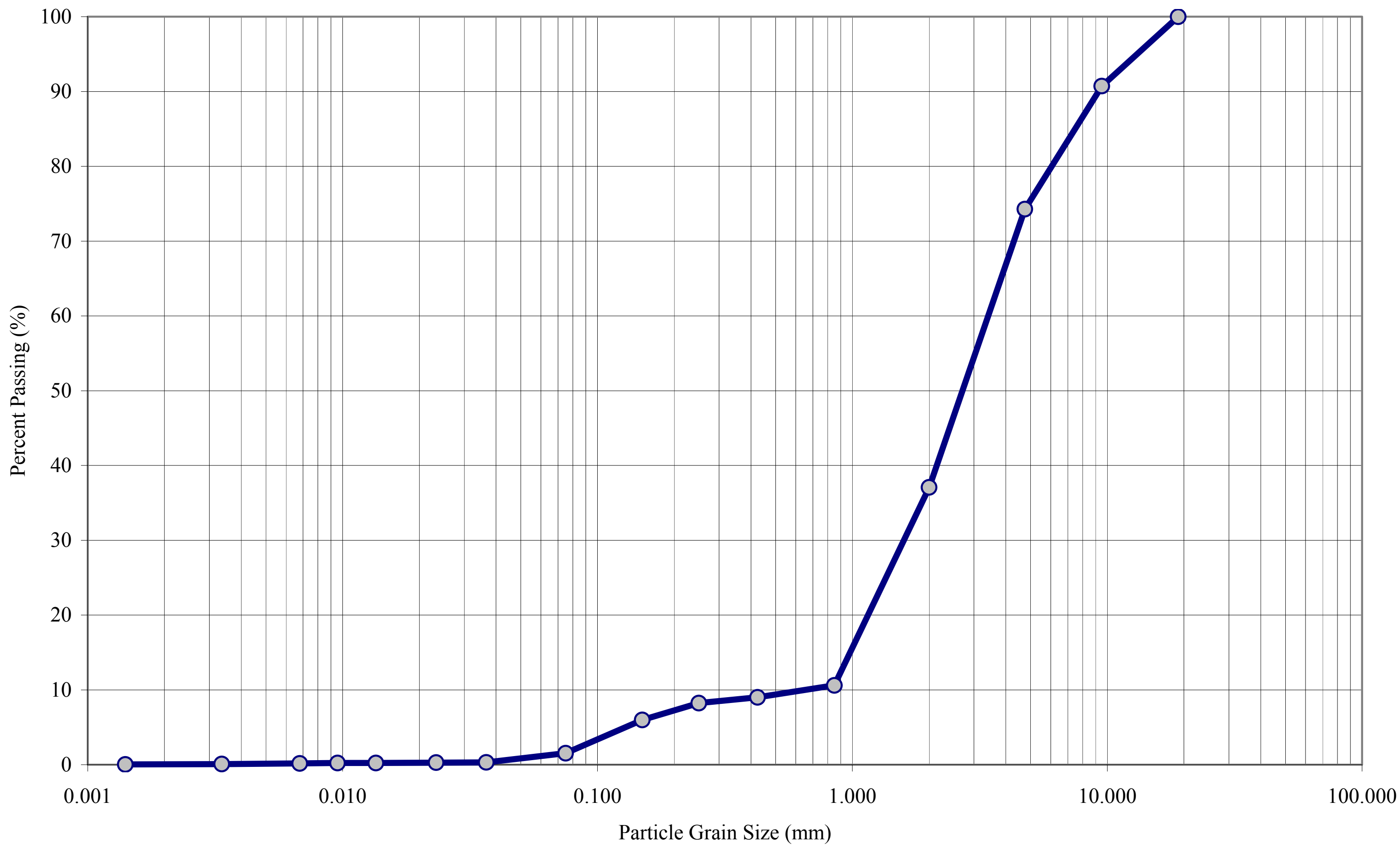
MFCS-1 Particle Size Distribution



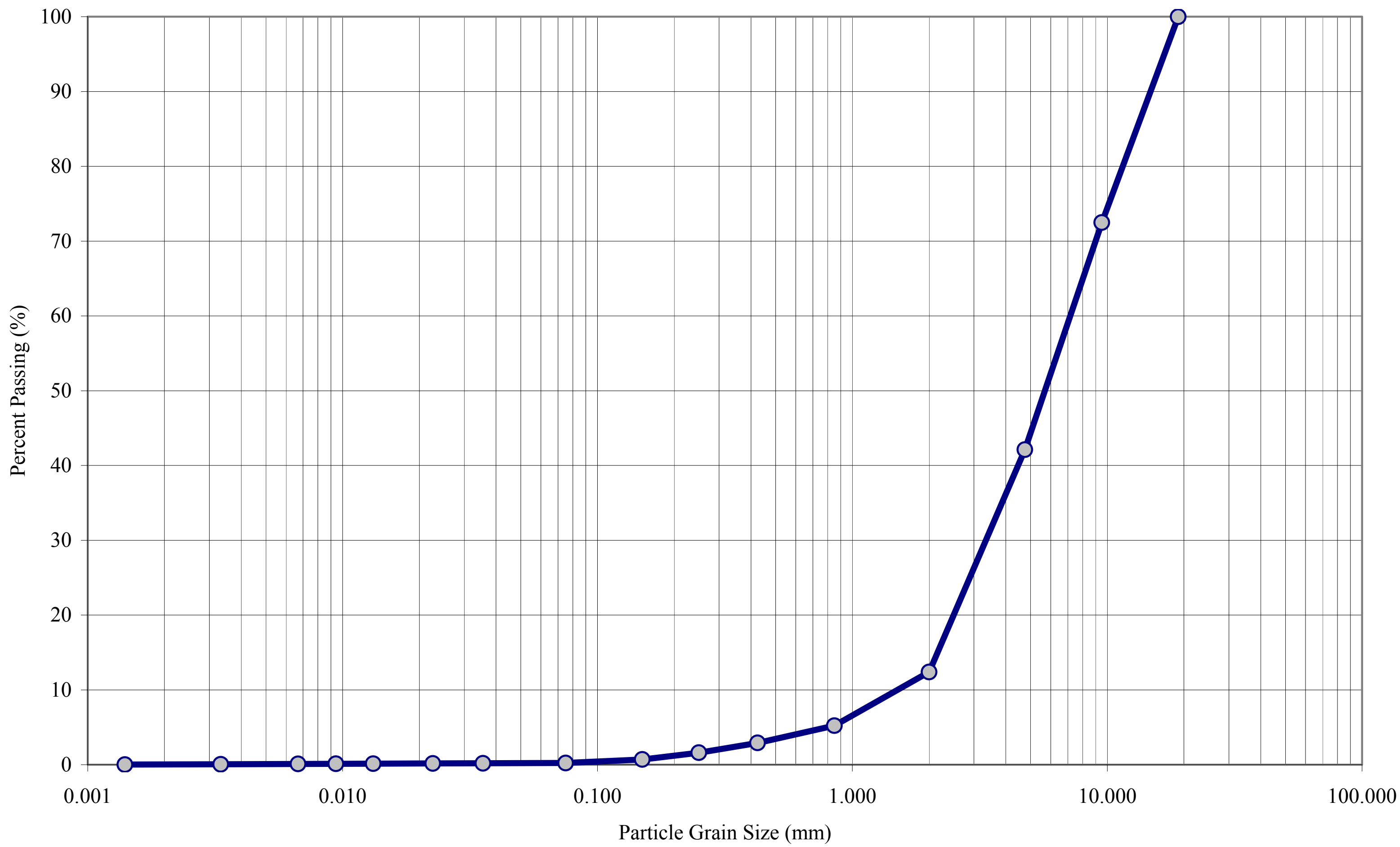
MFCS-10 Particle Size Distribution



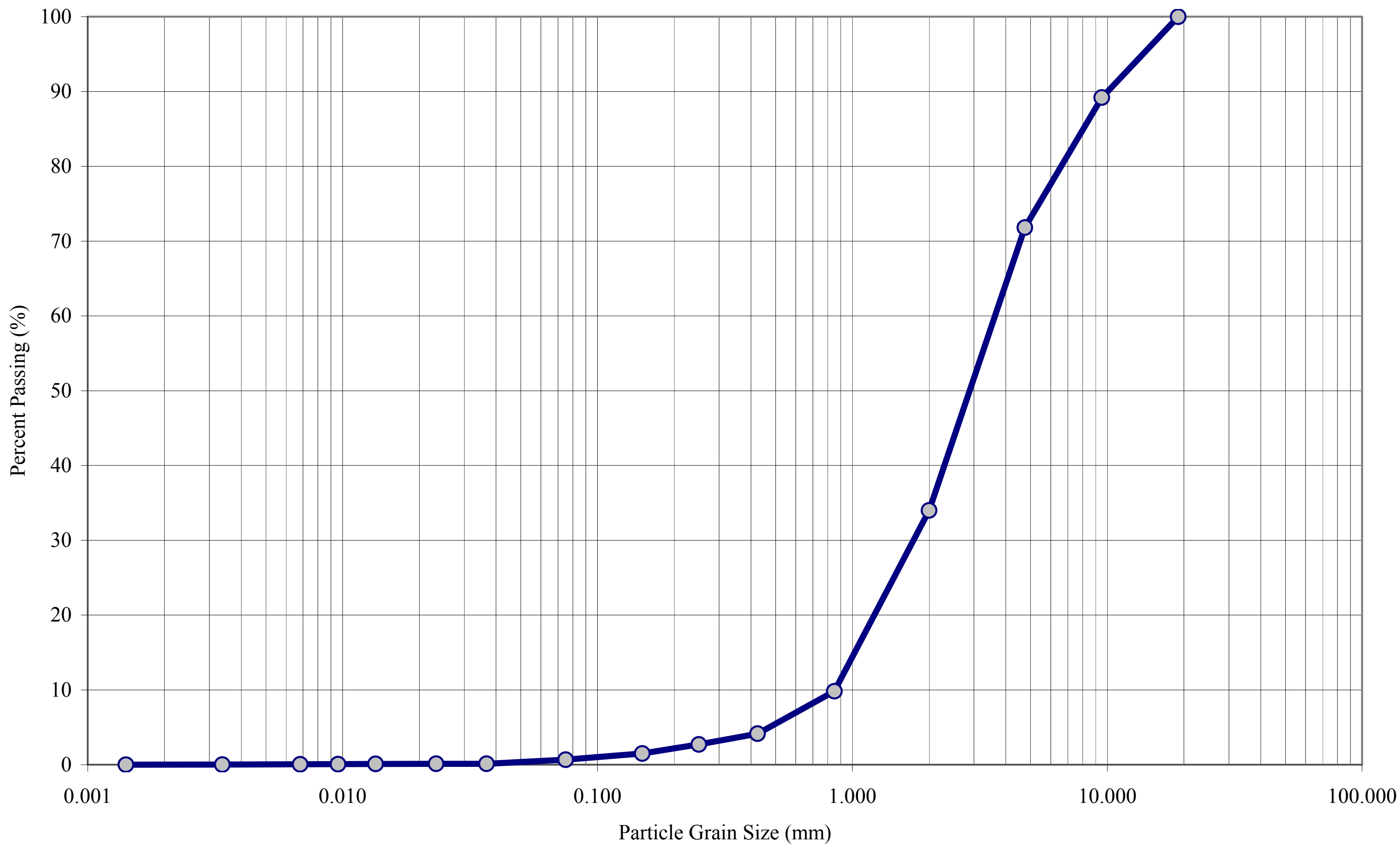
RC-1 Particle Size Distribution



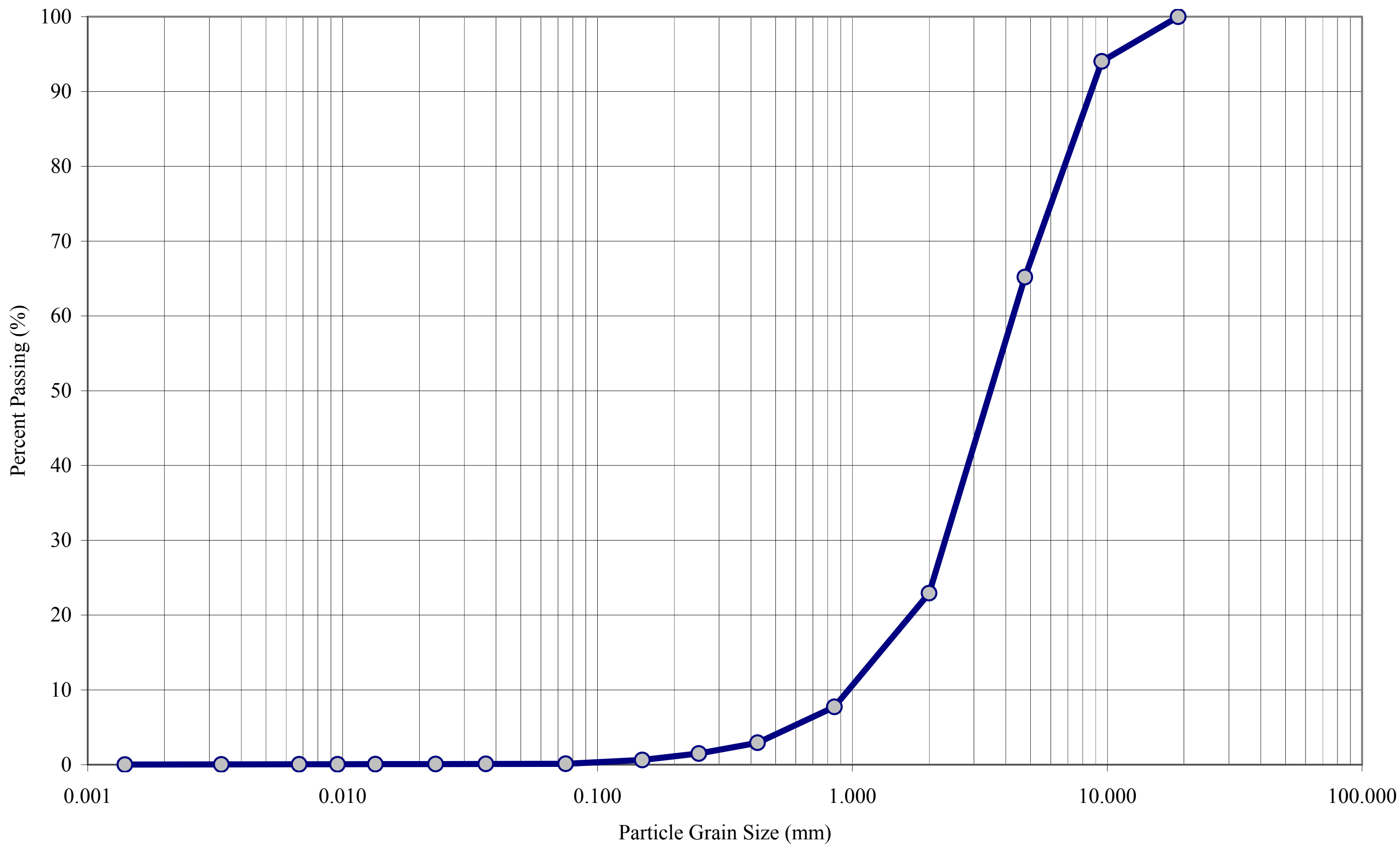
RC-2 Particle Size Distribution



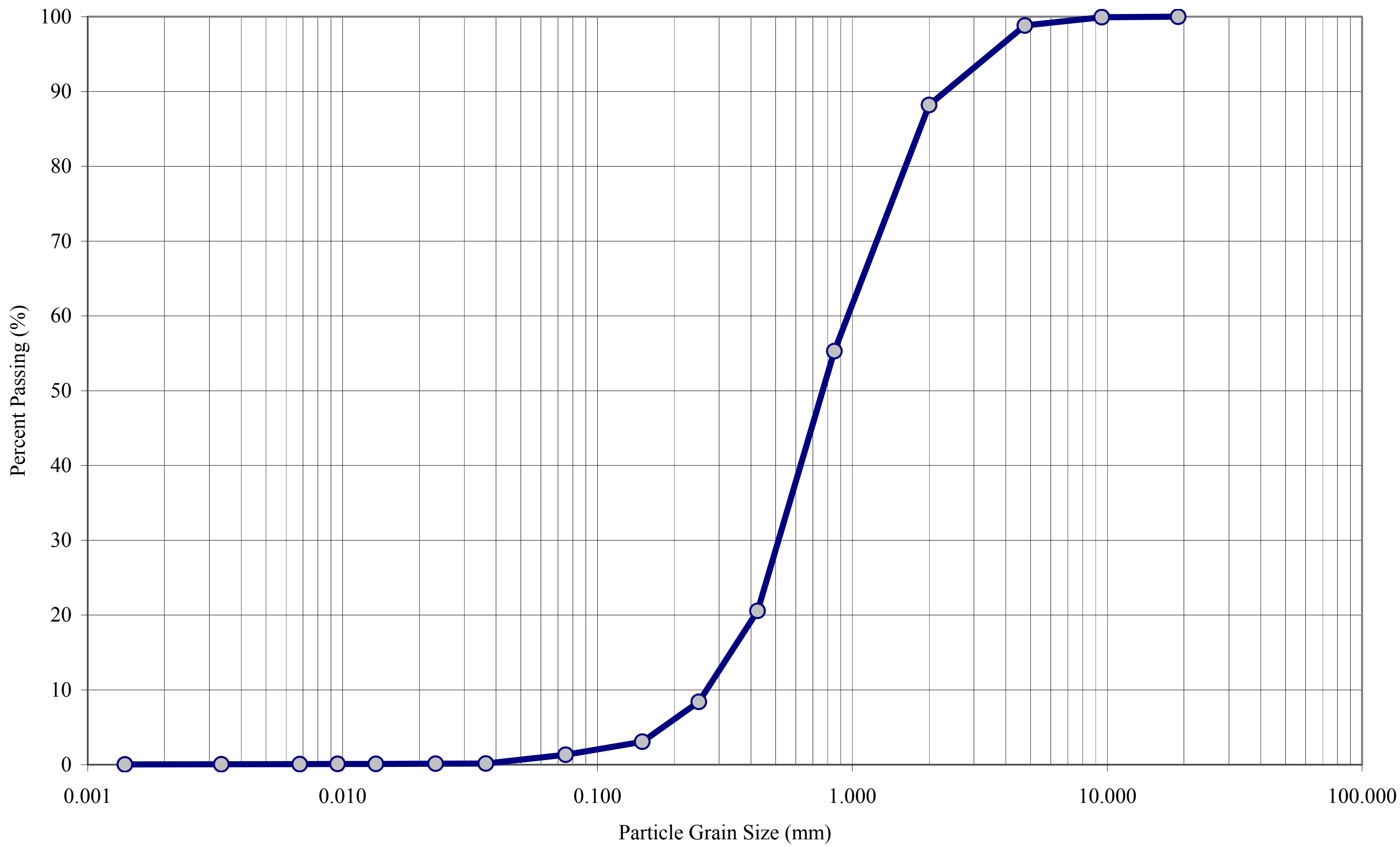
RC-3 Particle Size Distribution



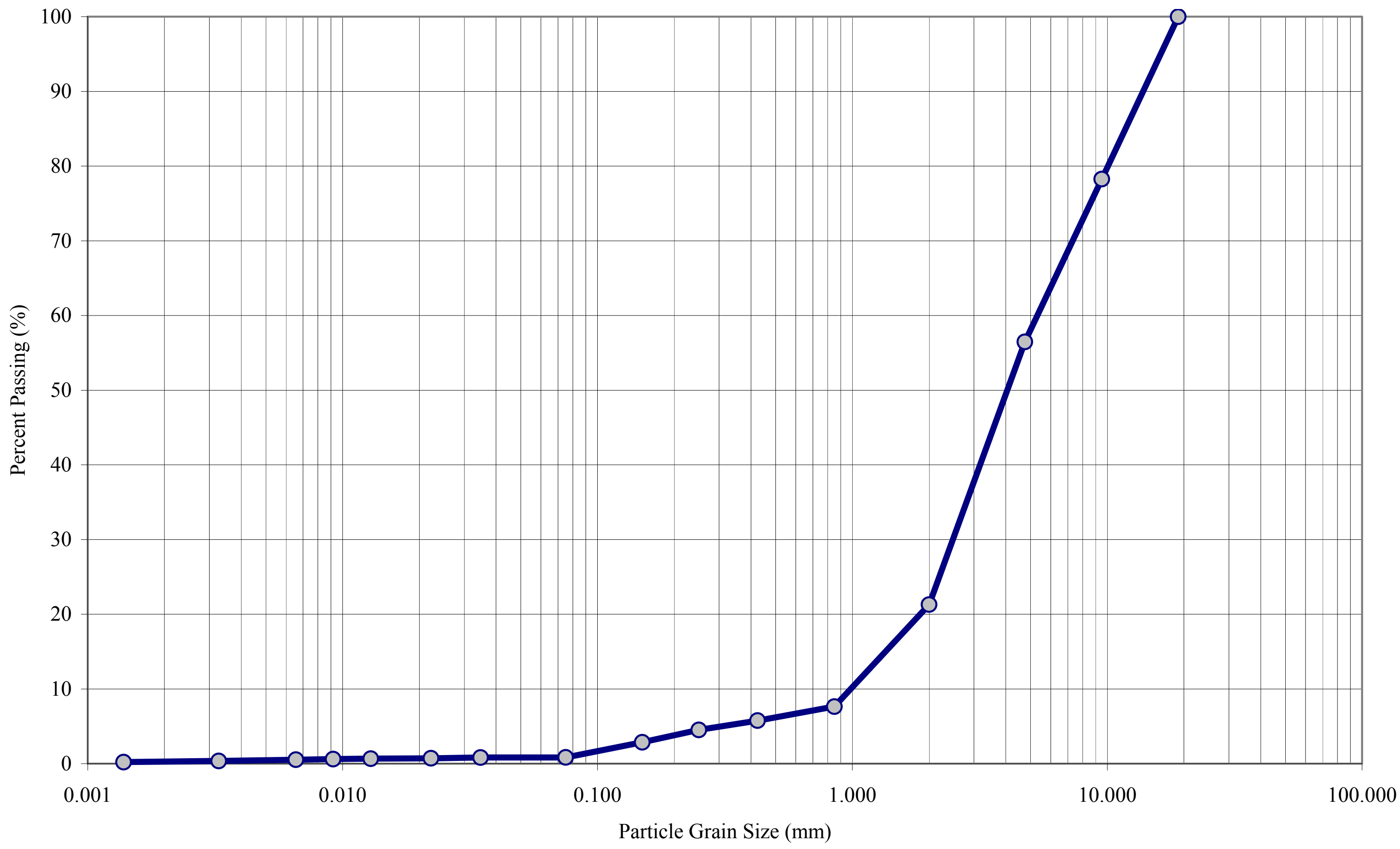
JC-1 Particle Size Distribution



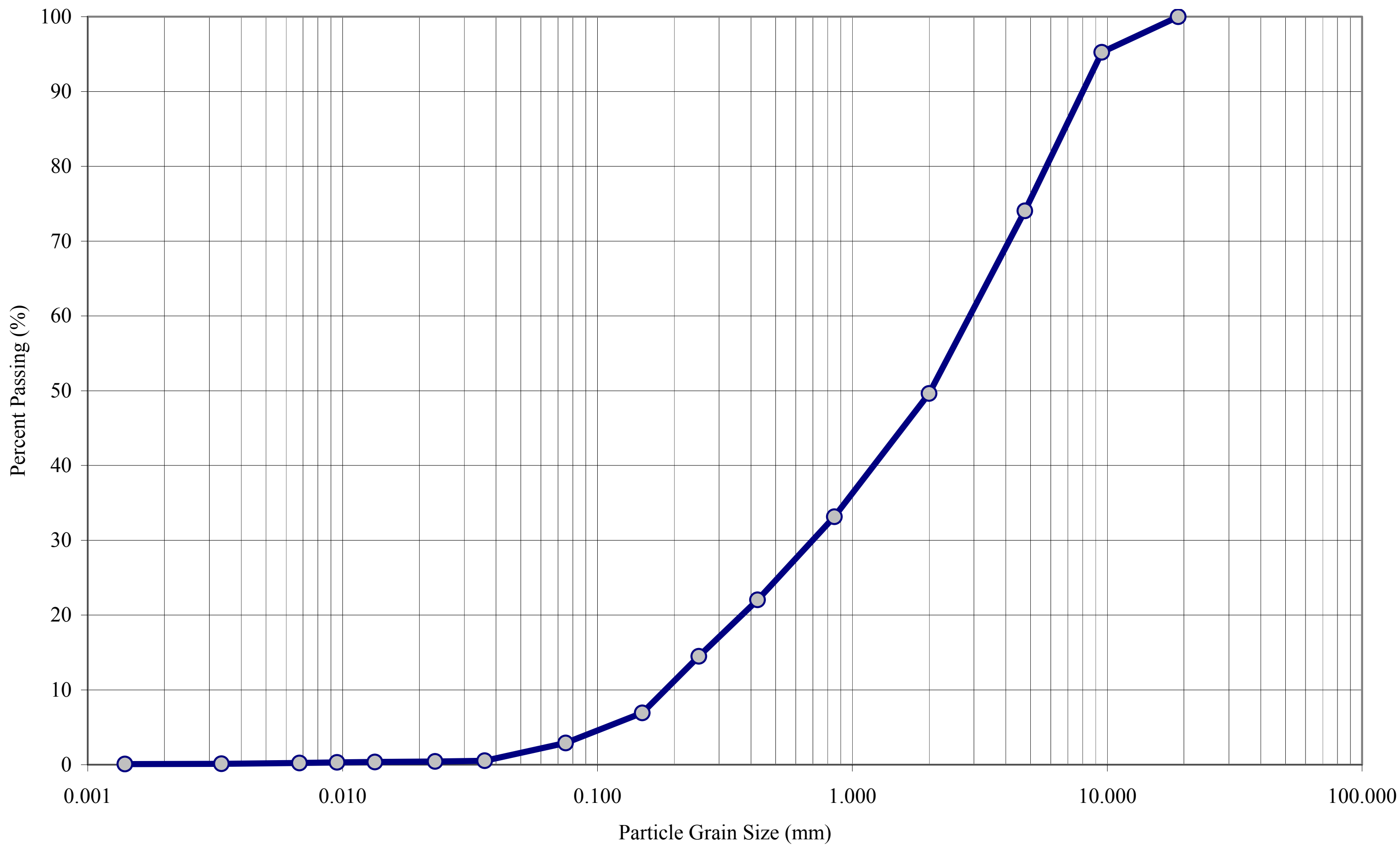
JC-3 Particle Size Distribution

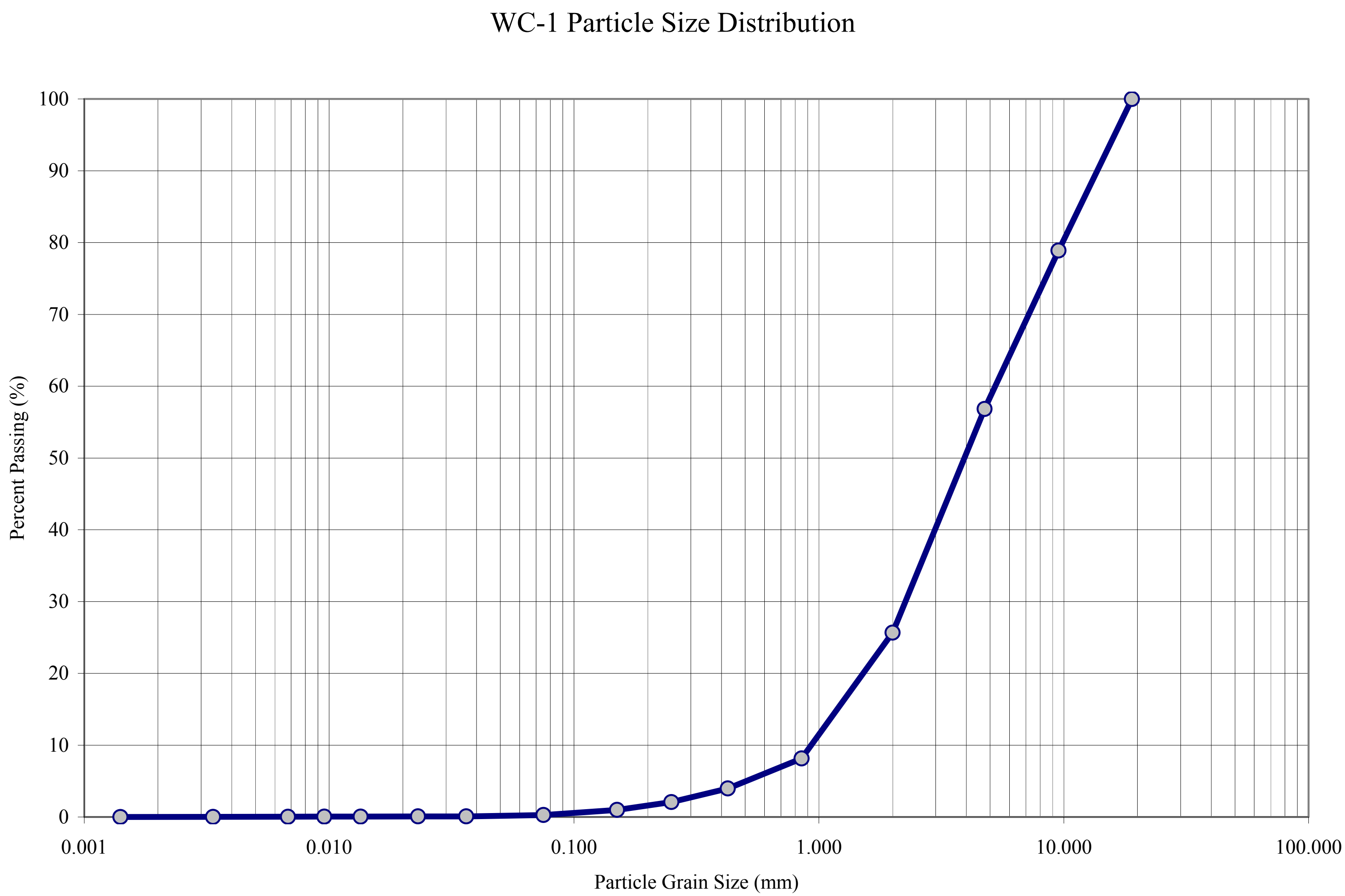


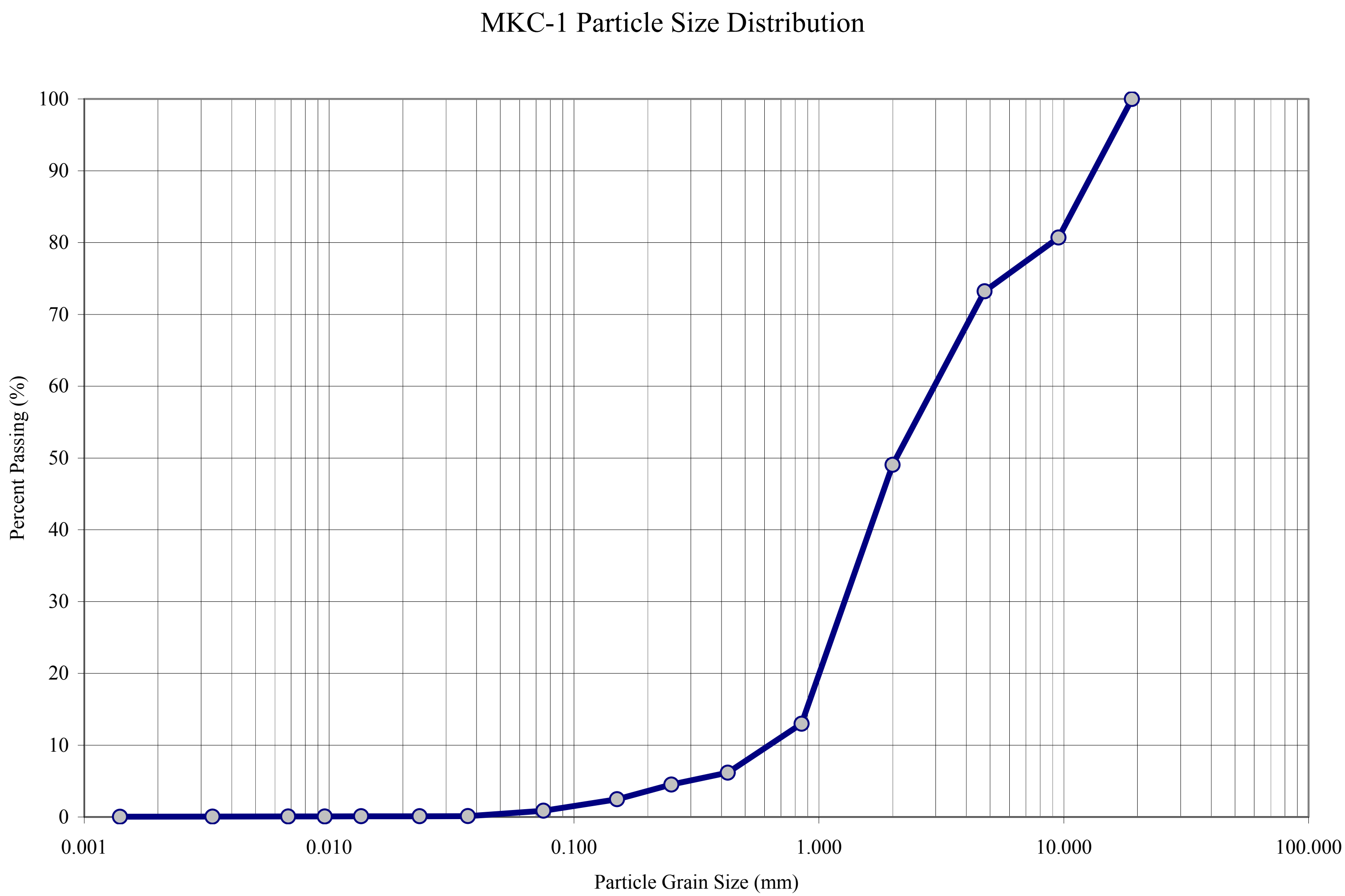
SB-1 Particle Size Distribution



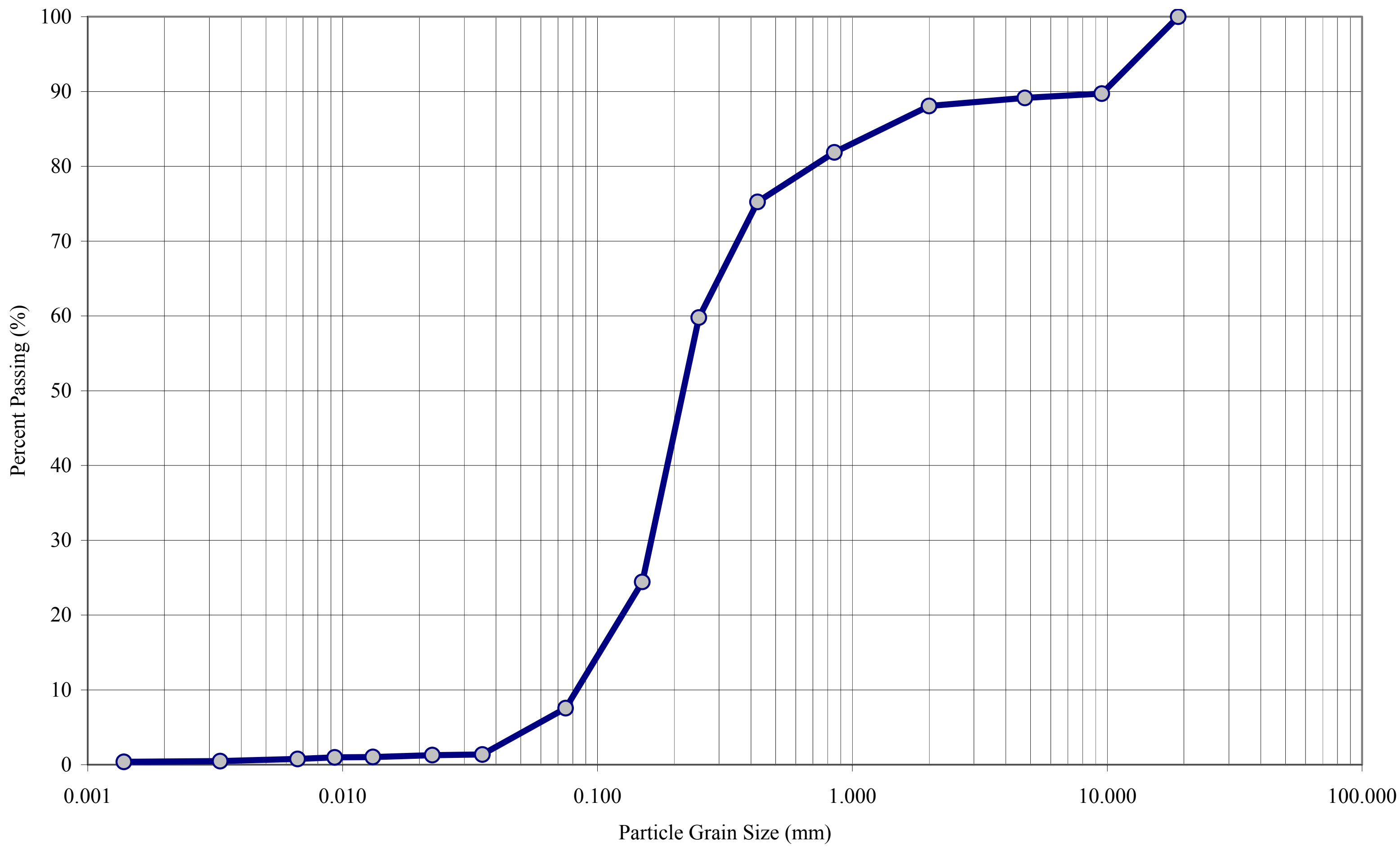
PCC-1 Particle Size Distribution

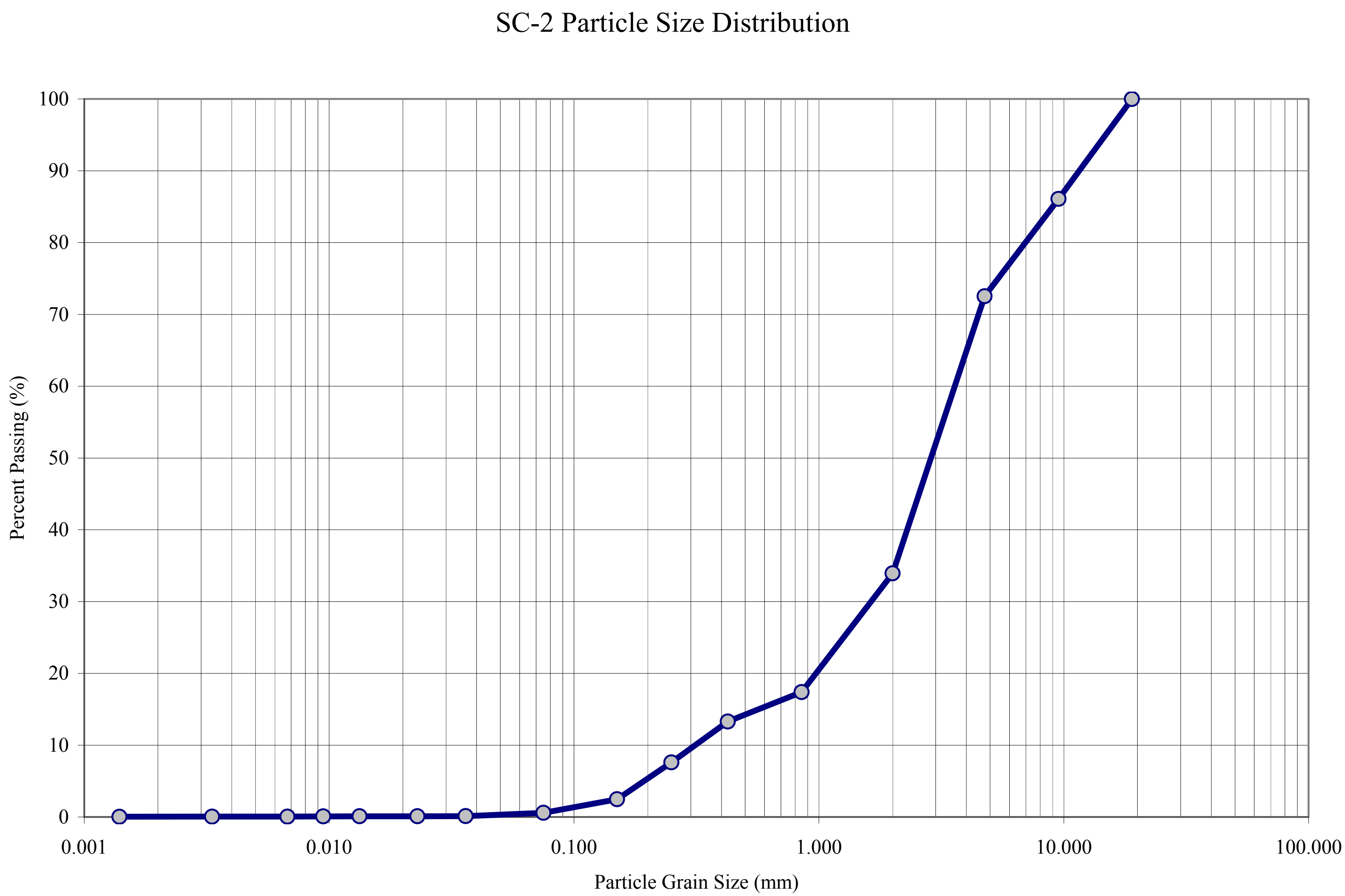



WC-1 Particle Size Distribution
100
90
80
70
60
50
40
30
20
10
0
Percent Passing (%)
0.001
0.010
0.100
1.000
10.000
100.000
Particle Grain Size (mm)

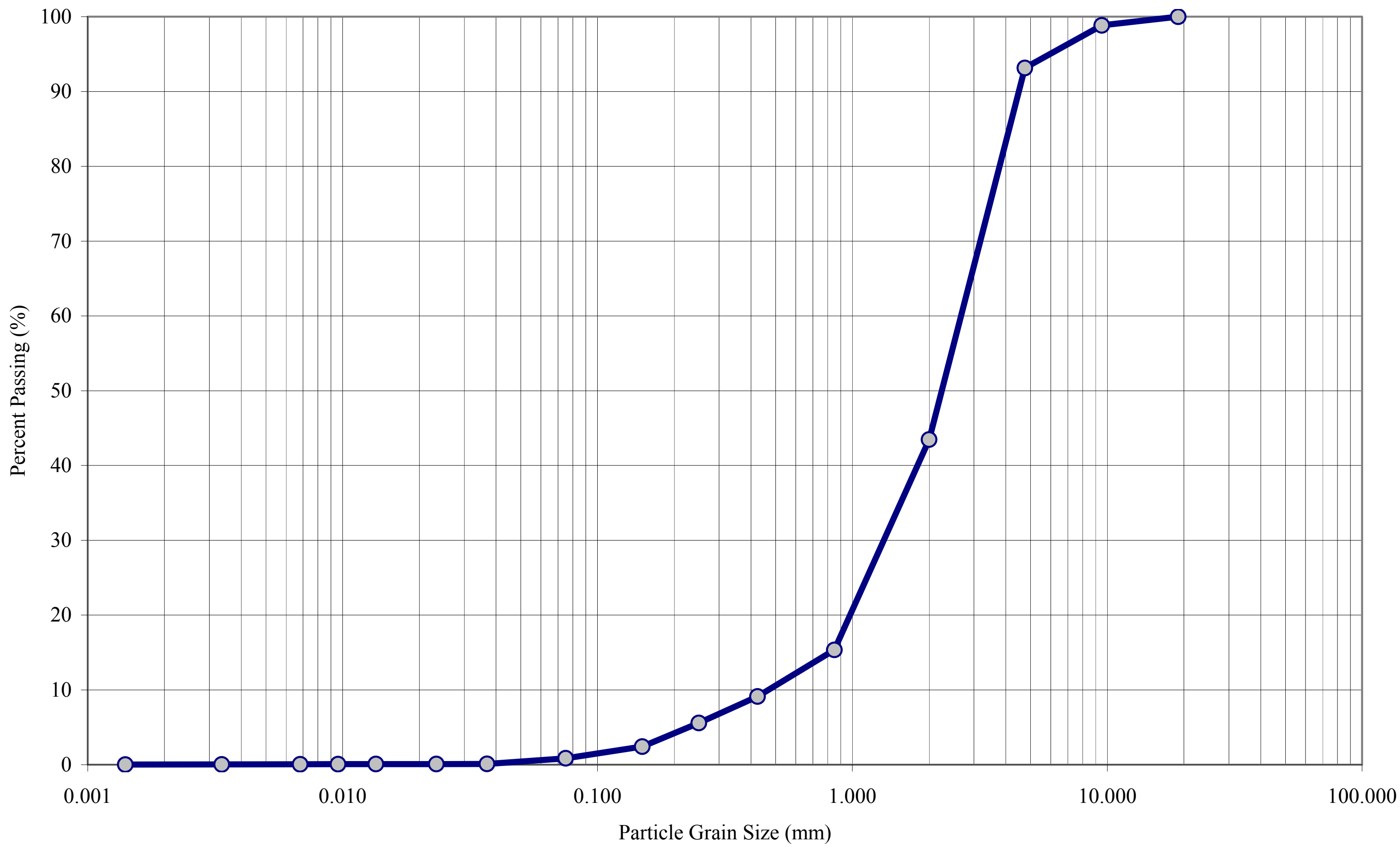

MKC-1 Particle Size Distribution
Percent Passing (%)
100
90
80
70
60
50
40
30
20
10
0
0.001
0.010
0.100
1.000
10.000
100.000
Particle Grain Size (mm)

SC-1 Particle Size Distribution

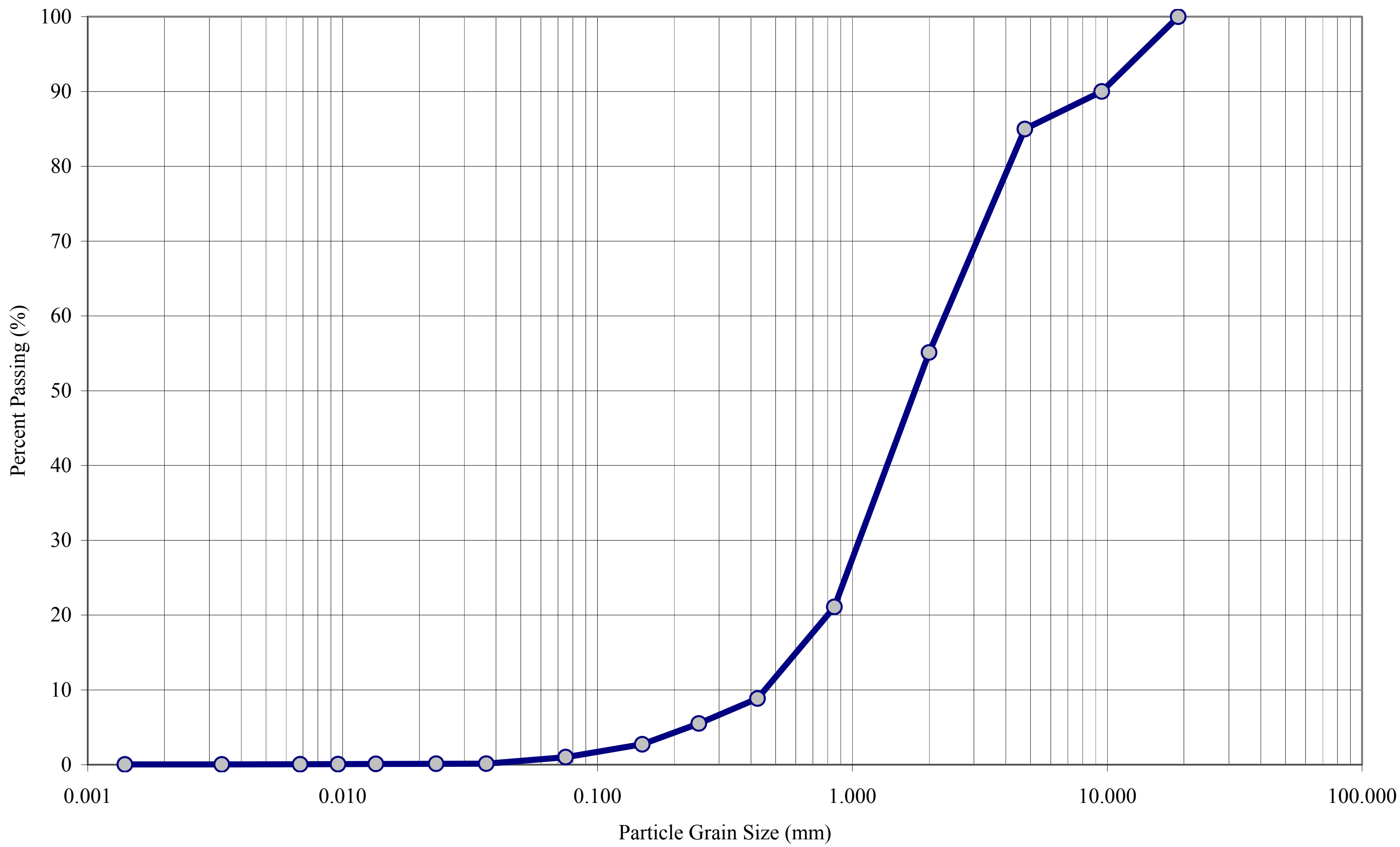


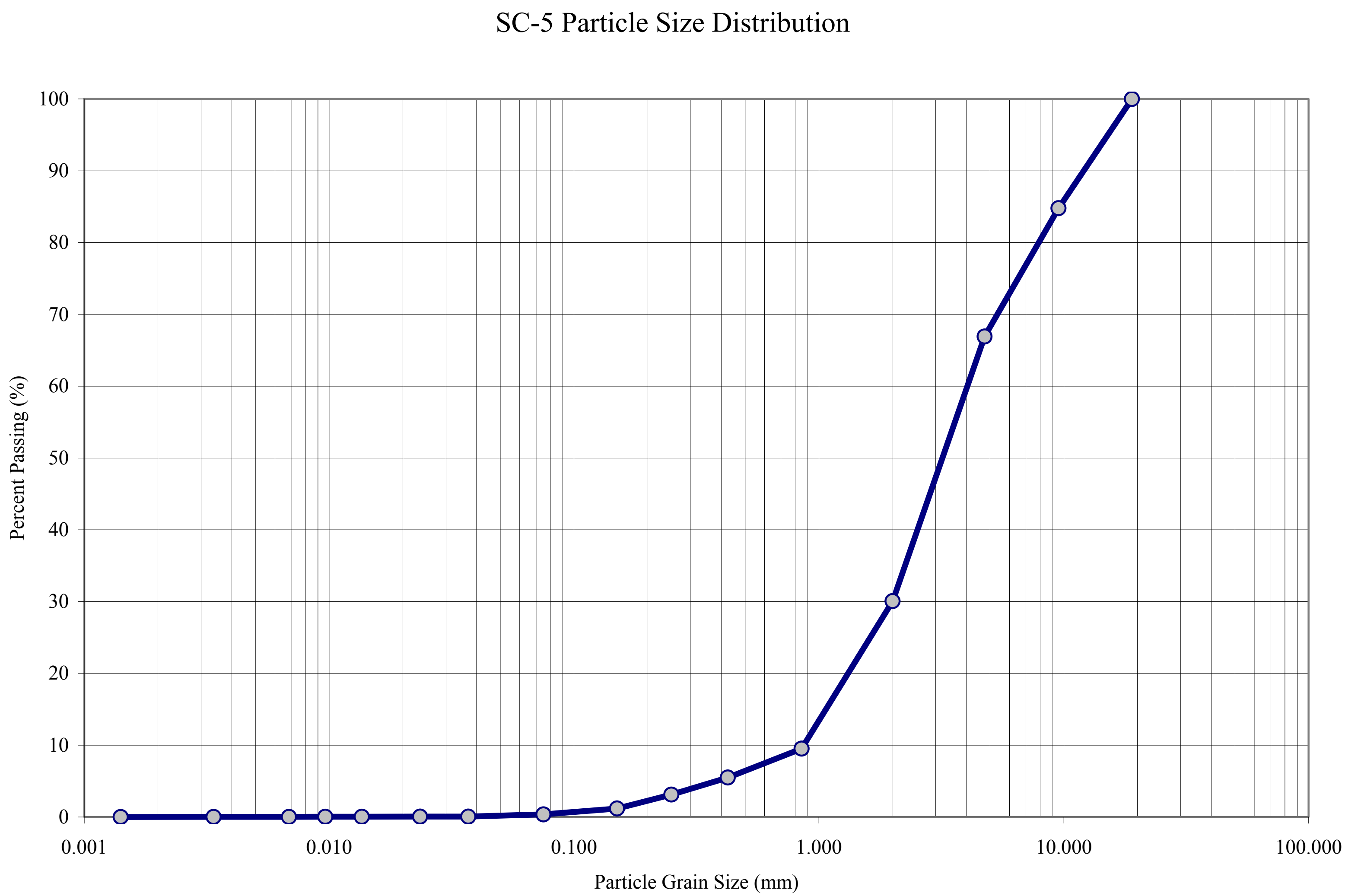

SC-2 Particle Size Distribution
Percent Passing (%)
100
90
80
70
60
50
40
30
20
10
0
0.001
0.010
0.100
1.000
10.000
100.000
Particle Grain Size (mm)

SC-3 Particle Size Distribution

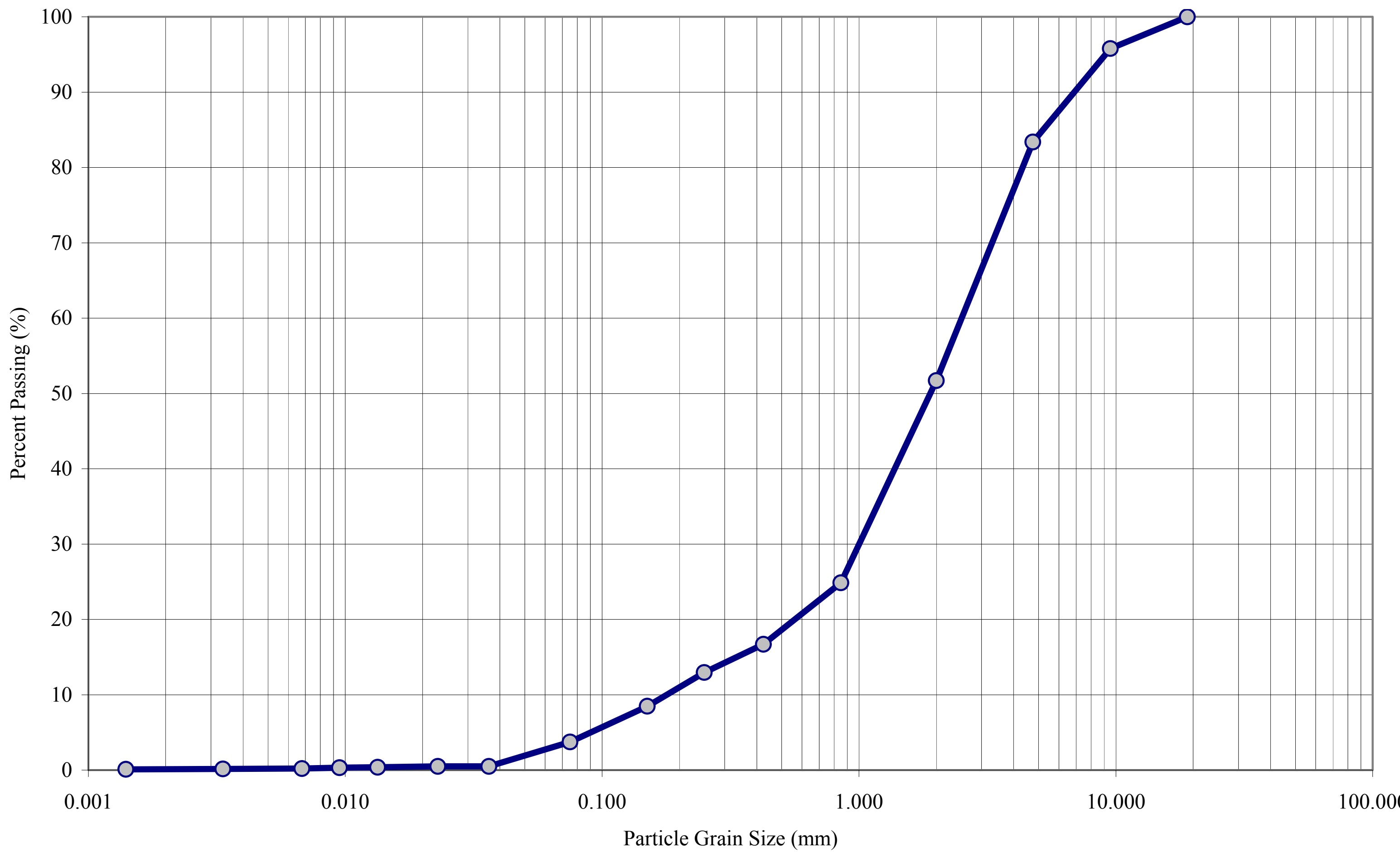


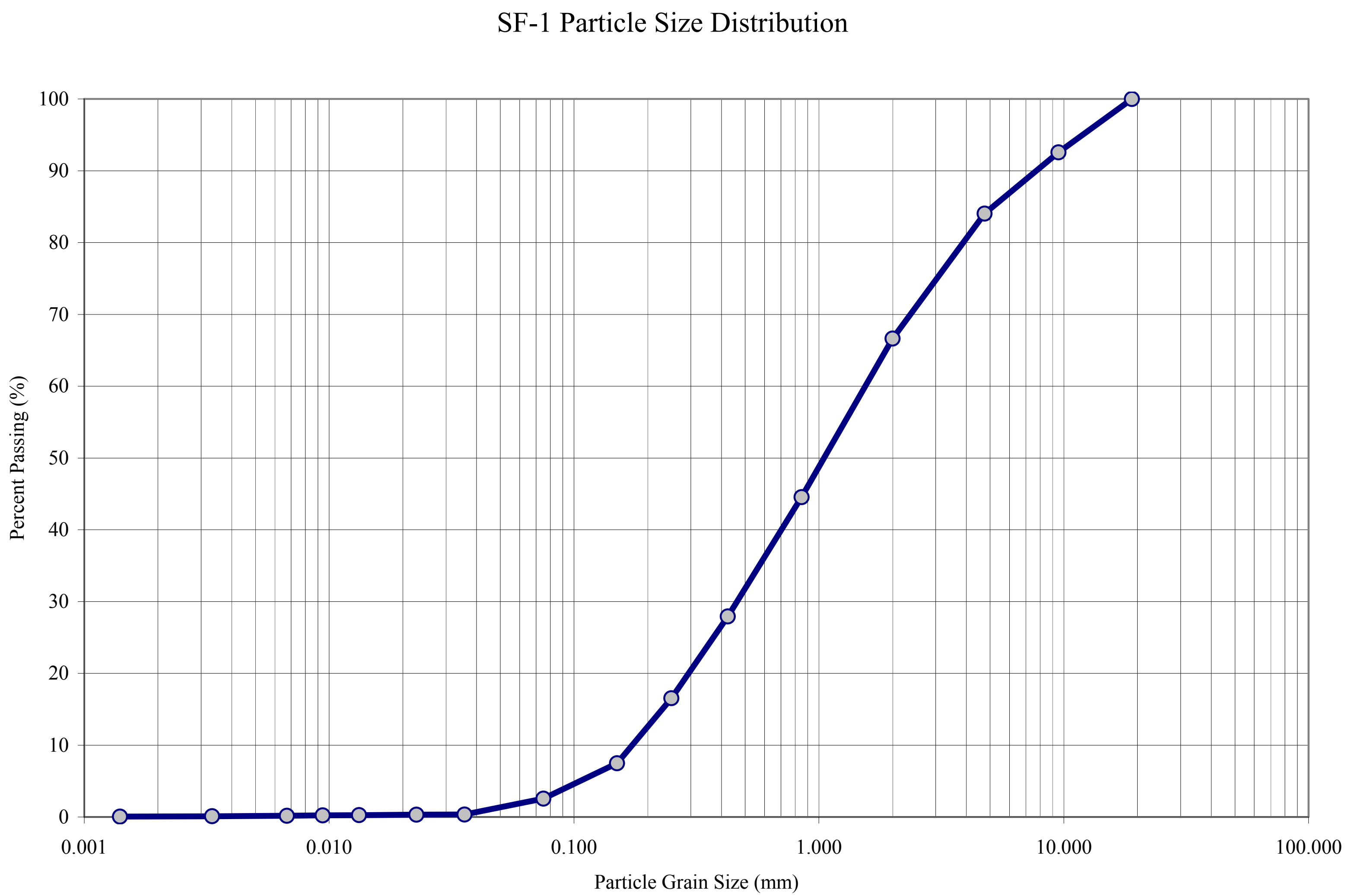
SC-4 Particle Size Distribution



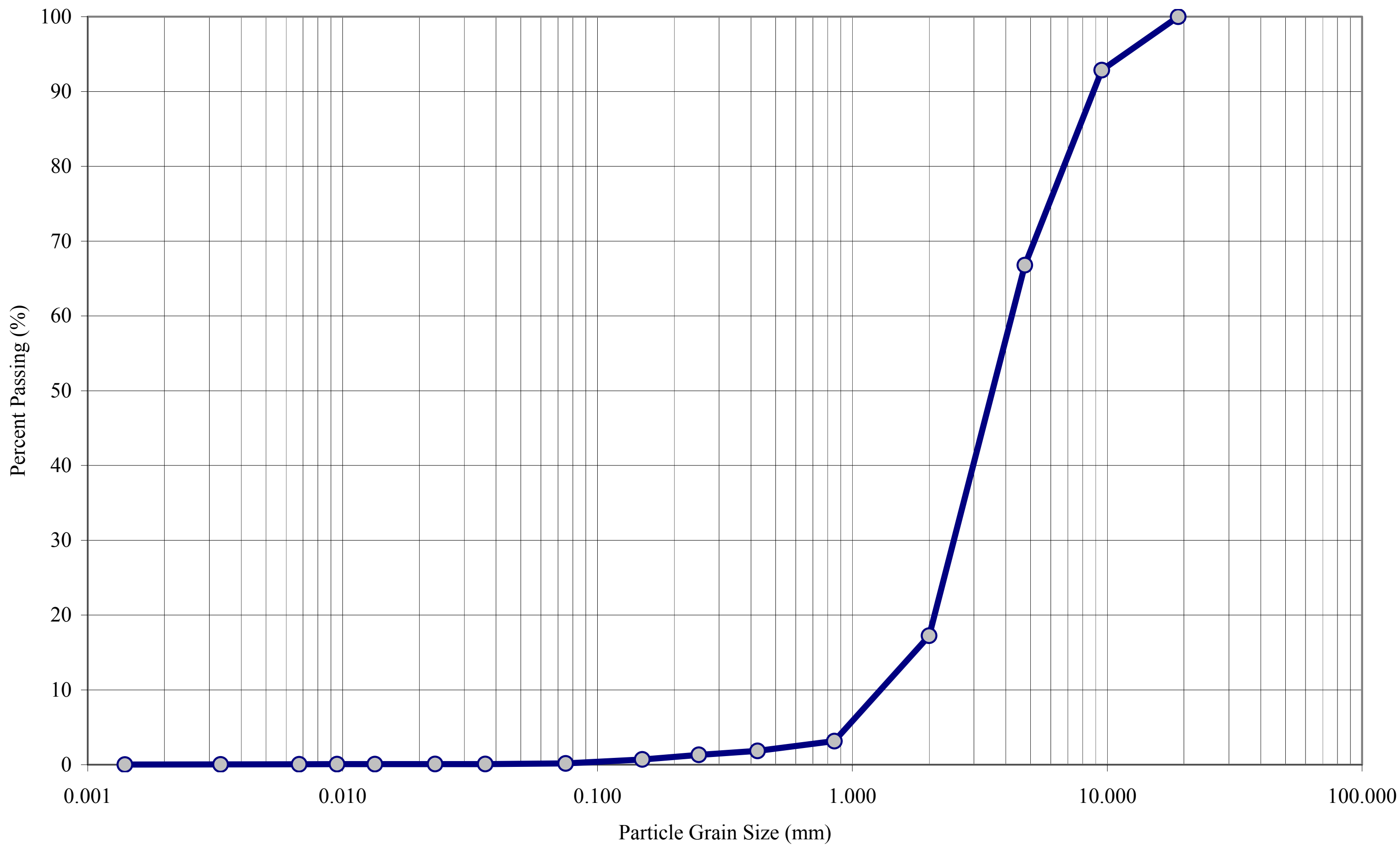

SC-5 Particle Size Distribution
Percent Passing (%)
100
90
80
70
60
50
40
30
20
10
0
0.001
0.010
0.100
1.000
10.000
100.000
Particle Grain Size (mm)

SC-6 Particle Size Distribution




SF-1 Particle Size Distribution
100
90
80
70
60
50
40
30
20
10
0
Percent Passing (%)
0.001
0.010
0.100
1.000
10.000
100.000
Particle Grain Size (mm)

SHC-1 Particle Size Distribution



Appendix C

Stage-Discharge Data

Stage-Discharge Summary for Brimstone Creek

Sample Number	Sample Date (M/D/Y)	Sample Time (H:M)	Measured Stream Discharge (ft^3/sec)	Stream Stage Reading (feet)	Measured Stream Discharge (m^3/sec)	Stream Stage Reading (meters)
1	11/9/2007	2:00 PM	0.43	1.17	0.012	0.36
2	12/11/2007	3:00 PM	2.16	1.27	0.061	0.39
3	1/10/2008	3:40 PM	12.68	1.45	0.359	0.44
4	1/11/2008	9:15 AM	145.62	2.41	4.124	0.73
5	1/26/2008	12:30 PM	9.94	1.35	0.281	0.41
6	1/21/2008	12:00 PM	6.91	1.33	0.196	0.41
7	2/1/2008	7:30 AM	17.35	1.48	0.491	0.45
8	2/6/2008	8:00 AM	141.69	2.50	4.012	0.76

Stage-Discharge Summary for Montgomery Fork

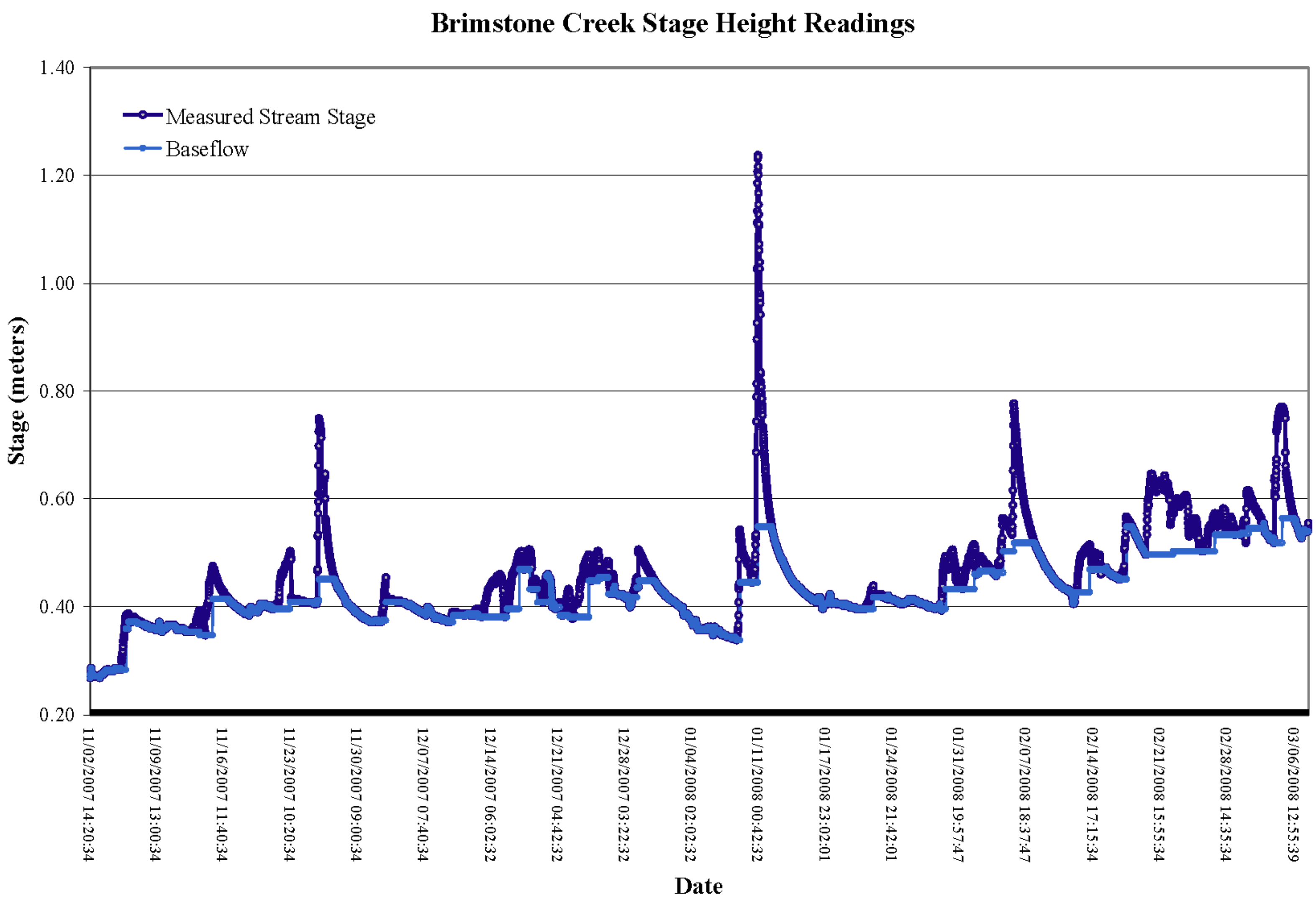
Sample Number	Sample Date (M/D/Y)	Sample Time (H:M)	Measured Stream Discharge (ft^3/sec)	Stream Stage Reading (feet)	Measured Stream Discharge (m^3/sec)	Stream Stage Reading (meters)
1	7/18/2007	12:45 PM	1.20	0.34	0.034	0.10
2	7/18/2007	1:15 PM	1.50	0.33	0.043	0.10
3	10/18/2007	1:30 PM	0.28	0.13	0.008	0.04
4	12/11/2007	1:15 PM	8.54	0.42	0.242	0.13
5	1/7/2008	2:30 PM	11.81	0.48	0.334	0.15
6	1/10/2008	2:00 PM	69.19	1.01	1.959	0.31
7	1/11/2008	12:00 PM	219.63	2.26	6.219	0.69
8	1/26/2008	2:00 PM	16.30	0.62	0.462	0.19
9	2/1/2008	9:10 AM	37.20	0.71	1.053	0.22

Stage-Discharge Summary for Ligias Fork

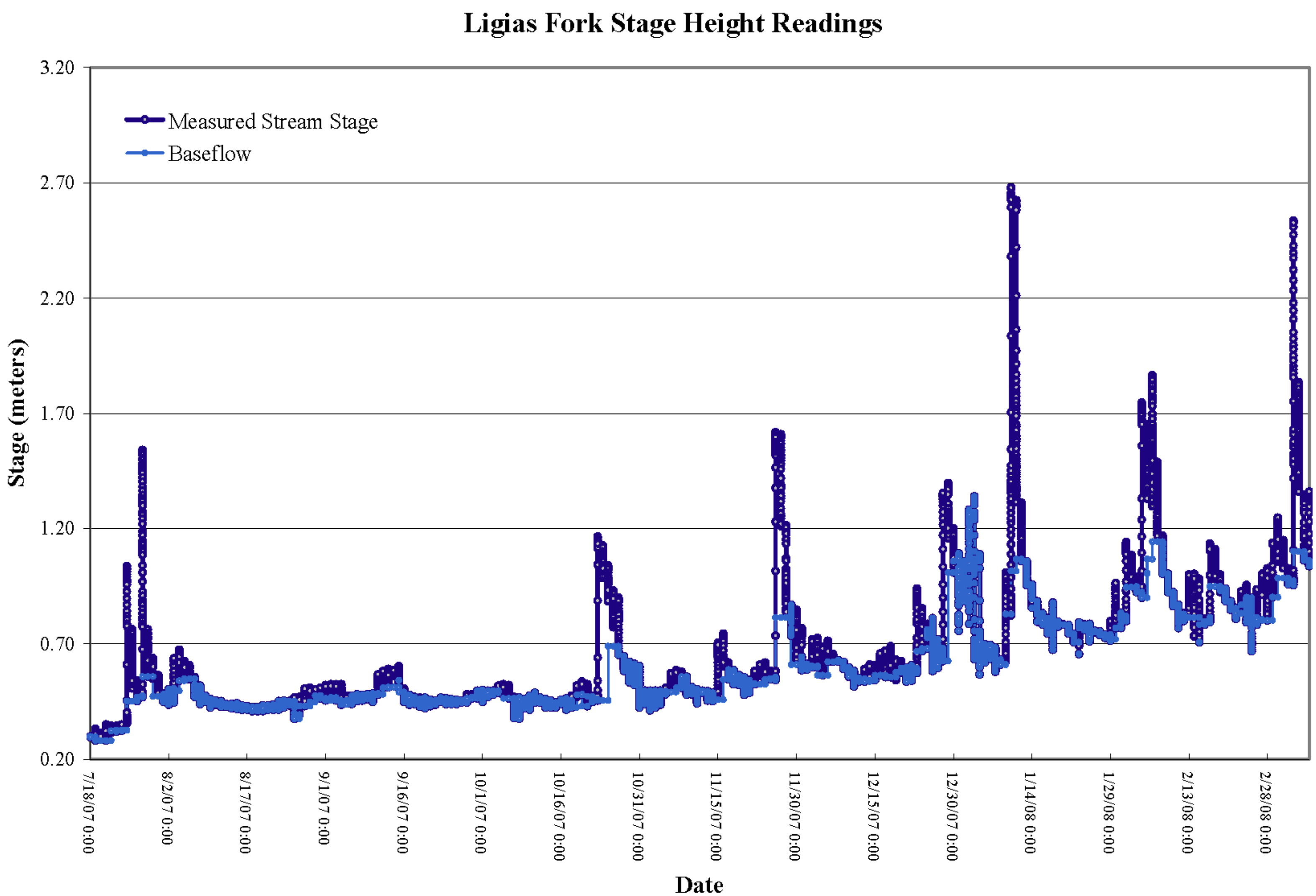
Sample Number	Sample Date (M/D/Y)	Sample Time (H:M)	Measured Stream Discharge (ft^3/sec)	Stream Stage Reading (feet)	Measured Stream Discharge (m^3/sec)	Stream Stage Reading (meters)
1	7/18/2007	5:30 PM	2.23	0.97	0.063	0.30
2	10/18/2007	3:00 PM	0.92	1.40	0.026	0.43
3	11/30/2007	12:00 PM	21.21	2.13	0.601	0.65
4	12/11/2007	10:15 AM	7.43	1.80	0.210	0.55
5	1/7/2008	9:00 AM	14.14	2.12	0.401	0.65
6	1/10/2008	11:00 AM	114.77	2.84	3.250	0.87
7	1/21/2008	2:00 PM	23.32	2.57	0.660	0.78
8	1/24/2008	11:15 AM	25.83	2.55	0.731	0.78
9	1/30/2008	12:00 PM	37.23	2.59	1.054	0.79
10	2/7/2008	1:30 PM	132.76	4.16	3.759	1.27

Stage-Discharge Summary for Smokey Creek

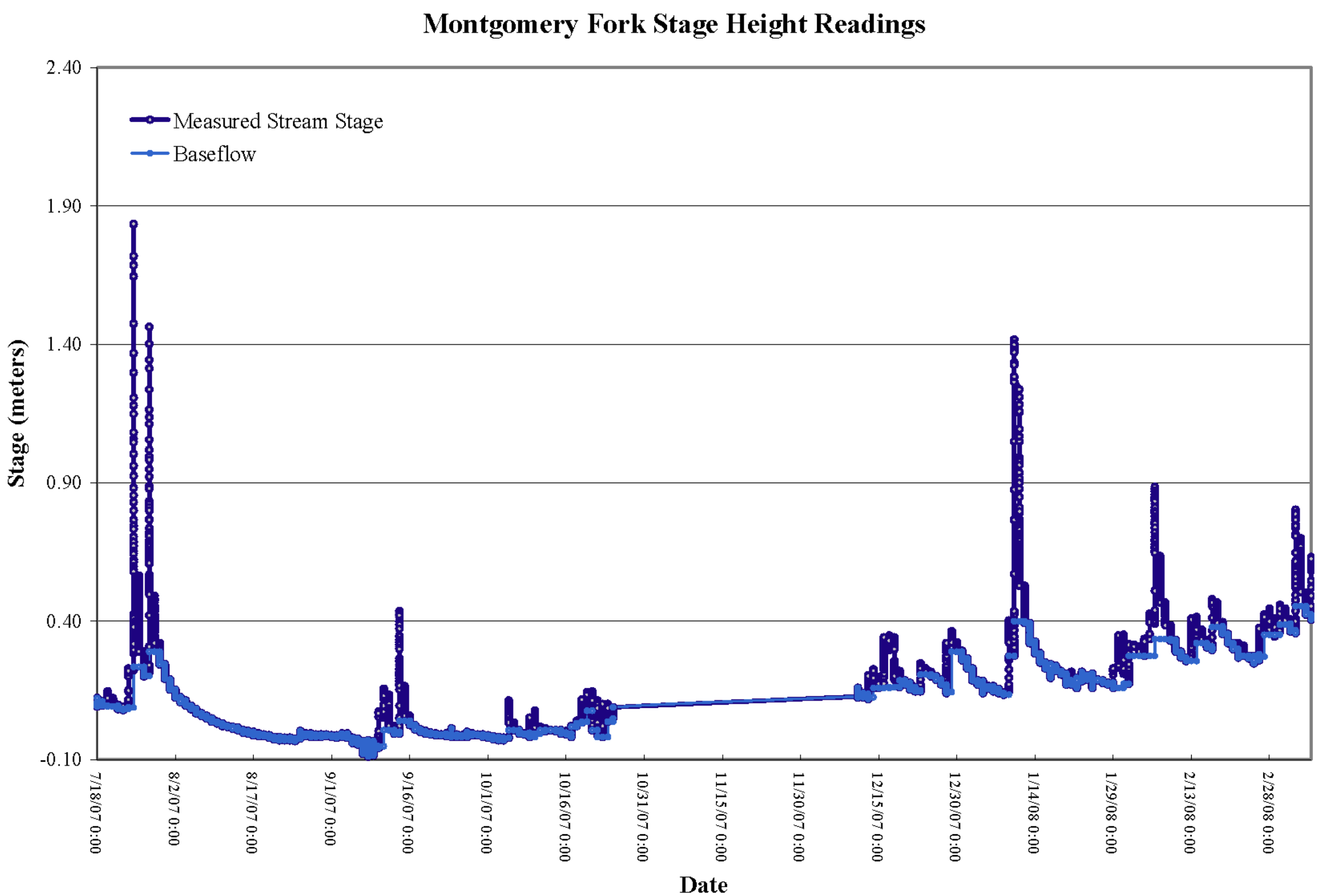
Sample Number	Sample Date (M/D/Y)	Sample Time (H:M)	Measured Stream Discharge (ft^3/sec)	Stream Stage Reading (feet)	Measured Stream Discharge (m^3/sec)	Stream Stage Reading (meters)
1	10/22/2007	10:00 AM	0.31	0.50	0.009	0.15
2	11/21/2007	12:00 PM	4.81	0.82	0.136	0.25
3	11/30/2007	12:30 PM	23.39	1.18	0.662	0.36
4	12/11/2007	12:45 PM	9.30	0.77	0.263	0.23
5	1/7/2008	2:30 PM	13.62	0.99	0.386	0.30
6	1/10/2008	12:45 PM	138.98	2.52	3.935	0.77
7	1/26/2008	2:30 PM	23.20	1.05	0.657	0.32
8	1/30/2008	10:30 AM	35.87	1.14	1.016	0.35
9	2/1/2008	10:00 AM	50.72	1.53	1.436	0.47

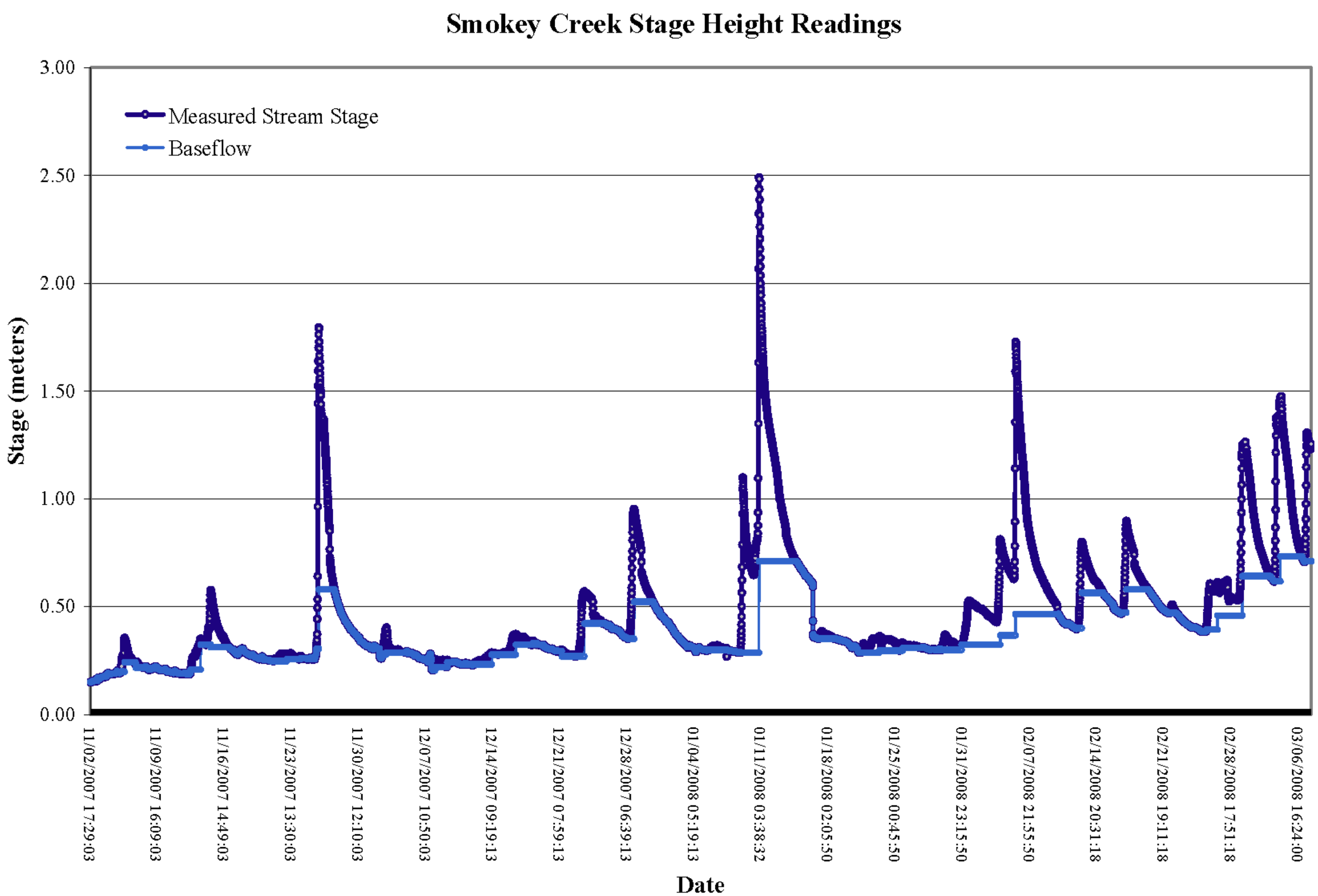


Brimstone Creek Stage Height Readings
Measured Stream Stage
Baseflow
Stage (meters)
1.40
1.20
1.00
0.80
0.60
0.40
0.20
11/02/2007 14:20:34
11/09/2007 13:00:34
11/16/2007 11:40:34
11/23/2007 10:20:34
11/30/2007 09:00:34
12/07/2007 07:40:34
12/14/2007 06:02:32
12/21/2007 04:42:32
12/28/2007 03:22:32
01/04/2008 02:02:32
01/11/2008 00:42:32
01/17/2008 23:02:01
01/24/2008 21:42:01
01/31/2008 19:57:47
02/07/2008 18:37:47
02/14/2008 17:15:34
02/21/2008 15:55:34
02/28/2008 14:35:34
03/06/2008 12:55:39
Date



Ligias Fork Stage Height Readings
Measured Stream Stage
Baseflow
Stage (meters)
3.20
2.70
2.20
1.70
1.20
0.70
0.20
7/18/07 0:00
8/2/07 0:00
8/17/07 0:00
9/1/07 0:00
9/16/07 0:00
10/1/07 0:00
10/16/07 0:00
10/31/07 0:00
11/15/07 0:00
11/30/07 0:00
12/15/07 0:00
12/30/07 0:00
1/14/08 0:00
1/29/08 0:00
2/13/08 0:00
2/28/08 0:00
Date


Montgomery Fork Stage Height Readings
Measured Stream Stage
Baseflow
Stage (meters)
2.40
1.90
1.40
0.90
0.40
-0.10
7/18/07 0:00
8/2/07 0:00
8/17/07 0:00
9/1/07 0:00
9/16/07 0:00
10/1/07 0:00
10/16/07 0:00
10/31/07 0:00
11/15/07 0:00
11/30/07 0:00
12/15/07 0:00
12/30/07 0:00
1/14/08 0:00
1/29/08 0:00
2/13/08 0:00
2/28/08 0:00
Date


Smokey Creek Stage Height Readings
Measured Stream Stage
Baseflow
Stage (meters)
3.00
2.50
2.00
1.50
1.00
0.50
0.00
11/02/2007 17:29:03
11/09/2007 16:09:03
11/16/2007 14:49:03
11/23/2007 13:30:03
11/30/2007 12:10:03
12/07/2007 10:50:03
12/14/2007 09:19:13
12/21/2007 07:59:13
12/28/2007 06:39:13
01/04/2008 05:19:13
01/11/2008 03:38:32
01/18/2008 02:05:50
01/25/2008 00:45:50
01/31/2008 23:15:50
02/07/2008 21:55:50
02/14/2008 20:31:18
02/21/2008 19:11:18
02/28/2008 17:51:18
03/06/2008 16:24:00
Date

Appendix D

Surface Runoff Data Tables

Brimstone Creek Measured Runoff Summary

Date (mm/dd/yyyy)	Surface Runoff (mm)	Average Daily Runoff Discharge (cms)	Peak Discharge (cms)	Runoff (Mg or m3)
11/2/2007	0.000	0.000	0.00	0
11/3/2007	0.000	0.000	0.00	0
11/4/2007	0.000	0.000	0.00	0
11/5/2007	0.002	0.001	0.01	45
11/6/2007	0.134	0.034	0.11	2,915
11/7/2007	0.087	0.022	0.08	1,907
11/8/2007	0.000	0.000	0.02	0
11/9/2007	0.000	0.000	0.00	0
11/10/2007	0.000	0.000	0.00	0
11/11/2007	0.000	0.000	0.00	0
11/12/2007	0.000	0.000	0.01	0
11/13/2007	0.129	0.034	0.15	2,820
11/14/2007	0.433	0.111	0.42	9,443
11/15/2007	1.530	0.384	0.80	33,378
11/16/2007	0.241	0.060	0.39	5,260
11/17/2007	0.000	0.000	0.24	0
11/18/2007	0.000	0.000	0.16	0
11/19/2007	0.000	0.000	0.18	0
11/20/2007	0.000	0.000	0.20	0
11/21/2007	0.040	0.010	0.21	875
11/22/2007	1.488	0.380	0.84	32,453
11/23/2007	1.591	0.397	1.15	34,705
11/24/2007	0.050	0.013	0.26	1,101
11/25/2007	0.000	0.000	0.23	0
11/26/2007	8.769	2.231	5.16	191,247
11/27/2007	2.517	0.618	2.99	54,888
11/28/2007	0.000	0.000	0.49	0
11/29/2007	0.000	0.000	0.28	0
11/30/2007	0.000	0.000	0.16	0
12/1/2007	0.000	0.000	0.08	0
12/2/2007	0.039	0.011	0.16	855
12/3/2007	0.427	0.107	0.53	9,310
12/4/2007	0.042	0.010	0.24	914
12/5/2007	0.000	0.000	0.23	0

Brimstone Creek Measured Runoff Summary - CONTINUED				
Date (mm/dd/yyyy)	Surface Runoff (mm)	Average Daily Runoff Discharge (cms)	Peak Discharge (cms)	Runoff (Mg or m3)
12/6/2007	0.000	0.000	0.20	0
12/7/2007	0.000	0.000	0.16	0
12/8/2007	0.000	0.000	0.11	0
12/9/2007	0.000	0.000	0.06	0
12/10/2007	0.128	0.032	0.13	2,783
12/11/2007	0.041	0.010	0.11	895
12/12/2007	0.092	0.023	0.16	1,996
12/13/2007	0.458	0.117	0.36	9,990
12/14/2007	1.462	0.370	0.57	31,883
12/15/2007	1.014	0.253	0.61	22,119
12/16/2007	1.686	0.431	0.96	36,772
12/17/2007	1.354	0.339	1.15	29,523
12/18/2007	1.121	0.280	1.19	24,458
12/19/2007	0.508	0.128	0.57	11,069
12/20/2007	0.000	0.000	0.61	10
12/21/2007	0.237	0.061	0.23	5,162
12/22/2007	0.469	0.118	0.36	10,226
12/23/2007	1.468	0.375	0.80	32,014
12/24/2007	2.103	0.529	1.07	45,856
12/25/2007	1.329	0.333	1.15	28,990
12/26/2007	0.855	0.215	0.84	18,645
12/27/2007	0.000	0.000	0.39	10
12/28/2007	0.011	0.003	0.34	236
12/29/2007	1.496	0.381	1.19	32,619
12/30/2007	1.118	0.279	0.84	24,376
12/31/2007	0.028	0.006	0.53	611
1/1/2008	0.000	0.000	0.33	0
1/2/2008	0.000	0.000	0.24	0
1/3/2008	0.000	0.000	0.18	0
1/4/2008	0.000	0.000	0.05	0
1/5/2008	0.000	0.000	0.01	0
1/6/2008	0.000	0.000	0.01	0
1/7/2008	0.000	0.000	0.01	0
1/8/2008	0.252	0.074	1.54	5,494

Brimstone Creek Measured Runoff Summary - CONTINUED

Date (mm/dd/yyyy)	Surface Runoff (mm)	Average Daily Runoff Discharge (cms)	Peak Discharge (cms)	Runoff (Mg or m3)
1/9/2008	2.724	0.680	1.66	59,417
1/10/2008	16.362	4.236	20.79	356,847
1/11/2008	16.382	3.975	16.76	357,295
1/12/2008	0.332	0.080	2.25	7,245
1/13/2008	0.000	0.000	1.15	0
1/14/2008	0.000	0.000	0.64	0
1/15/2008	0.000	0.000	0.38	0
1/16/2008	0.000	0.000	0.29	0
1/17/2008	0.000	0.000	0.24	0
1/18/2008	0.000	0.000	0.31	0
1/19/2008	0.000	0.000	0.21	0
1/20/2008	0.000	0.000	0.20	0
1/21/2008	0.000	0.000	0.16	0
1/22/2008	0.382	0.097	0.38	8,338
1/23/2008	0.093	0.023	0.31	2,025
1/24/2008	0.000	0.000	0.29	0
1/25/2008	0.000	0.000	0.24	0
1/26/2008	0.000	0.000	0.26	0
1/27/2008	0.000	0.000	0.24	0
1/28/2008	0.000	0.000	0.21	0
1/29/2008	0.028	0.008	0.36	610
1/30/2008	2.240	0.570	1.15	48,857
1/31/2008	1.336	0.334	1.19	29,136
2/1/2008	1.457	0.371	1.15	31,779
2/2/2008	2.147	0.539	1.31	46,826
2/3/2008	0.732	0.183	1.00	15,967
2/4/2008	0.050	0.013	0.84	1,099
2/5/2008	2.684	0.681	1.93	58,537
2/6/2008	8.093	2.051	6.04	176,514
2/7/2008	4.075	1.020	3.15	88,885
2/8/2008	0.516	0.127	1.78	11,254
2/9/2008	0.000	0.000	1.11	0
2/10/2008	0.000	0.000	0.64	0
2/11/2008	0.000	0.000	0.42	0

Brimstone Creek Measured Runoff Summary - CONTINUED				
Date (mm/dd/yyyy)	Surface Runoff (mm)	Average Daily Runoff Discharge (cms)	Peak Discharge (cms)	Runoff (Mg or m3)
2/12/2008	0.003	0.000	0.36	69
2/13/2008	2.632	0.671	1.23	57,409
2/14/2008	1.862	0.466	1.31	40,618
2/15/2008	0.545	0.135	1.07	11,887
2/16/2008	0.000	0.000	0.76	0
2/17/2008	0.563	0.149	1.43	12,286
2/18/2008	0.845	0.207	1.97	18,429
2/19/2008	0.000	0.000	1.58	0
2/20/2008	4.710	1.201	2.95	102,719
2/21/2008	6.589	1.664	2.83	143,703
2/22/2008	5.417	1.362	2.95	118,147
2/23/2008	4.481	1.133	2.40	97,725
2/24/2008	3.690	0.928	2.48	80,468
2/25/2008	1.790	0.447	1.93	39,038
2/26/2008	1.122	0.288	1.78	24,478
2/27/2008	1.963	0.494	2.05	42,813
2/28/2008	1.303	0.328	2.09	28,417
2/29/2008	0.436	0.107	1.90	9,519
3/1/2008	1.728	0.441	2.60	37,678
3/2/2008	1.926	0.483	2.44	42,016
3/3/2008	0.175	0.043	1.97	3,822
3/4/2008	5.962	1.512	5.65	130,021
3/5/2008	10.901	2.727	5.84	237,743
3/6/2008	0.530	0.130	2.48	11,559
3/7/2008	0.033	0.010	1.66	727

Montgomery Fork Measured Runoff Summary				
Date (mm/dd/yyyy)	Surface Runoff (mm)	Average Daily Runoff Discharge (cms)	Peak Discharge (cms)	Runoff (Mg or m3)
7/19/2007	0.000	0.000	0.03	4
7/20/2007	0.242	0.162	0.29	13,902
7/21/2007	0.100	0.066	0.17	5,759
7/22/2007	0.000	0.000	0.03	0
7/23/2007	0.001	0.001	0.03	47
7/24/2007	0.280	0.194	1.14	16,099
7/25/2007	16.846	11.227	79.50	968,364
7/26/2007	2.789	1.833	4.82	160,313
7/27/2007	0.233	0.153	1.81	13,368
7/28/2007	13.015	8.673	54.20	748,165
7/29/2007	1.652	1.085	4.02	94,938
7/30/2007	0.118	0.076	2.14	6,793
7/31/2007	0.000	0.000	1.31	0
8/1/2007	0.000	0.000	0.52	0
8/2/2007	0.000	0.000	0.33	0
8/3/2007	0.000	0.000	0.18	0
8/4/2007	0.000	0.000	0.12	0
8/5/2007	0.000	0.000	0.03	0
8/6/2007	0.000	0.000	0.03	0
8/7/2007	0.000	0.000	0.02	0
8/8/2007	0.000	0.000	0.02	0
8/9/2007	0.000	0.000	0.01	0
8/10/2007	0.000	0.000	0.01	0
8/11/2007	0.000	0.000	0.01	0
8/12/2007	0.000	0.000	0.01	0
8/13/2007	0.000	0.000	0.01	0
8/14/2007	0.000	0.000	0.01	0
8/15/2007	0.000	0.000	0.01	0
8/16/2007	0.000	0.000	0.01	0
8/17/2007	0.000	0.000	0.01	0
8/18/2007	0.000	0.000	0.01	0
8/19/2007	0.000	0.000	0.00	0
8/20/2007	0.000	0.000	0.00	0
8/21/2007	0.000	0.000	0.00	0

Montgomery Fork Measured Runoff Summary - CONTINUED

Date (mm/dd/yyyy)	Surface Runoff (mm)	Average Daily Runoff Discharge (cms)	Peak Discharge (cms)	Runoff (Mg or m3)
8/22/2007	0.000	0.000	0.00	0
8/23/2007	0.000	0.000	0.00	0
8/24/2007	0.000	0.000	0.00	0
8/25/2007	0.000	0.000	0.00	0
8/26/2007	0.000	0.000	0.01	0
8/27/2007	0.000	0.000	0.01	0
8/28/2007	0.000	0.000	0.01	0
8/29/2007	0.000	0.000	0.01	0
8/30/2007	0.000	0.000	0.00	0
8/31/2007	0.000	0.000	0.01	0
9/1/2007	0.000	0.000	0.00	0
9/2/2007	0.000	0.000	0.00	0
9/3/2007	0.000	0.000	0.01	0
9/4/2007	0.000	0.000	0.01	0
9/5/2007	0.000	0.000	0.00	0
9/6/2007	0.000	0.000	0.00	0
9/7/2007	0.000	0.000	0.00	0
9/8/2007	0.000	0.000	0.00	0
9/9/2007	0.000	0.000	0.00	0
9/10/2007	0.005	0.004	0.02	301
9/11/2007	0.167	0.112	0.34	9,602
9/12/2007	0.045	0.028	0.23	2,565
9/13/2007	0.000	1.000	0.01	0
9/14/2007	1.298	0.867	3.42	74,632
9/15/2007	0.144	0.093	0.39	8,272
9/16/2007	0.000	0.000	0.02	0
9/17/2007	0.000	0.000	0.01	0
9/18/2007	0.000	0.000	0.01	0
9/19/2007	0.000	0.000	0.01	0
9/20/2007	0.000	0.000	0.01	0
9/21/2007	0.000	0.000	0.01	0
9/22/2007	0.000	0.000	0.01	0
9/23/2007	0.000	0.000	0.01	0
9/24/2007	0.000	0.000	0.01	0

Montgomery Fork Measured Runoff Summary - CONTINUED				
		Average Daily		
	Surface	Runoff	Peak	
Date	Runoff	Discharge	Discharge	Runoff
(mm/dd/yyyy)	(mm)	(cms)	(cms)	(Mg or m3)
9/25/2007	0.000	0.000	0.01	0
9/26/2007	0.000	0.000	0.00	0
9/27/2007	0.000	0.000	0.01	0
9/28/2007	0.000	0.000	0.01	0
9/29/2007	0.000	0.000	0.01	0
9/30/2007	0.000	0.000	0.01	0
10/1/2007	0.000	0.000	0.00	0
10/2/2007	0.000	0.000	0.00	0
10/3/2007	0.000	0.000	0.00	0
10/4/2007	0.000	0.000	0.00	0
10/5/2007	0.052	0.035	0.12	3,011
10/6/2007	0.001	0.001	0.01	53
10/7/2007	0.000	0.000	0.01	0
10/8/2007	0.000	0.000	0.01	0
10/9/2007	0.002	0.002	0.01	140
10/10/2007	0.009	0.006	0.02	506
10/11/2007	0.001	0.001	0.01	78
10/12/2007	0.000	0.000	0.01	14
10/13/2007	0.000	0.000	0.01	0
10/14/2007	0.000	0.000	0.01	0
10/15/2007	0.000	0.000	0.01	0
10/16/2007	0.000	0.000	0.01	2
10/17/2007	0.002	0.002	0.01	134
10/18/2007	0.001	0.001	0.01	45
10/19/2007	0.036	0.025	0.13	2,060
10/20/2007	0.193	0.129	0.28	11,076
10/21/2007	0.193	0.128	0.29	11,078
10/22/2007	0.064	0.042	0.12	3,696
10/23/2007	0.008	0.005	0.06	434
10/24/2007	0.023	0.015	0.03	1,298
10/25/2007	0.013	0.011	0.03	748
12/13/2007	0.269	0.180	0.79	15,459
12/14/2007	0.539	0.355	1.10	30,977
12/15/2007	0.073	0.049	0.65	4,168

Montgomery Fork Measured Runoff Summary - CONTINUED				
Date (mm/dd/yyyy)	Surface Runoff (mm)	Average Daily Runoff Discharge (cms)	Peak Discharge (cms)	Runoff (Mg or m3)
12/16/2007	1.998	1.342	2.38	114,827
12/17/2007	2.726	1.813	2.44	156,711
12/18/2007	1.861	1.228	2.38	106,995
12/19/2007	0.335	0.220	1.12	19,241
12/20/2007	0.000	0.000	0.50	0
12/21/2007	0.000	0.000	0.45	0
12/22/2007	0.000	0.000	0.37	0
12/23/2007	0.455	0.305	1.34	26,145
12/24/2007	0.355	0.236	1.14	20,403
12/25/2007	0.000	0.000	1.05	0
12/26/2007	0.000	0.000	0.72	0
12/27/2007	0.000	0.000	0.52	0
12/28/2007	0.592	0.407	2.14	34,027
12/29/2007	1.176	0.772	2.61	67,595
12/30/2007	0.317	0.208	2.18	18,208
12/31/2007	0.002	0.002	1.84	100
1/1/2008	0.000	0.000	1.54	0
1/2/2008	0.000	0.000	1.14	0
1/3/2008	0.000	0.000	0.50	0
1/4/2008	0.000	0.000	0.48	0
1/5/2008	0.000	0.000	0.37	0
1/6/2008	0.000	0.000	0.39	0
1/7/2008	0.000	0.000	0.34	0
1/8/2008	0.003	0.002	0.28	181
1/9/2008	1.333	0.890	3.05	76,632
1/10/2008	10.415	7.196	51.09	598,688
1/11/2008	11.640	6.986	38.86	669,094
1/12/2008	0.861	0.563	4.42	49,479
1/13/2008	0.000	0.000	2.95	0
1/14/2008	0.000	0.000	2.21	0
1/15/2008	0.000	0.000	1.74	0
1/16/2008	0.000	0.000	1.37	0
1/17/2008	0.000	0.000	1.31	0
1/18/2008	0.000	0.000	1.24	0

Montgomery Fork Measured Runoff Summary - CONTINUED				
Date (mm/dd/yyyy)	Surface Runoff (mm)	Average Daily Runoff Discharge (cms)	Peak Discharge (cms)	Runoff (Mg or m3)
1/19/2008	0.000	0.000	1.12	0
1/20/2008	0.000	0.000	0.92	0
1/21/2008	0.201	0.134	1.05	11,563
1/22/2008	0.000	0.000	0.59	0
1/23/2008	0.000	0.000	1.05	0
1/24/2008	0.000	0.000	0.79	0
1/25/2008	0.000	0.000	0.92	0
1/26/2008	0.000	0.000	0.52	0
1/27/2008	0.000	0.000	0.50	0
1/28/2008	0.000	0.000	0.45	0
1/29/2008	0.051	0.039	1.14	2,916
1/30/2008	2.549	1.705	2.44	146,503
1/31/2008	1.837	1.213	2.48	105,592
2/1/2008	1.159	0.769	2.11	66,599
2/2/2008	0.617	0.410	2.08	35,451
2/3/2008	0.391	0.259	2.01	22,468
2/4/2008	0.264	0.179	2.31	15,193
2/5/2008	2.241	1.497	3.32	128,842
2/6/2008	5.298	3.539	14.80	304,564
2/7/2008	3.336	2.206	5.59	191,785
2/8/2008	1.434	0.948	3.75	82,418
2/9/2008	0.348	0.227	2.85	19,976
2/10/2008	0.000	0.000	2.28	0
2/11/2008	0.000	0.000	1.81	0
2/12/2008	0.013	0.009	1.57	723
2/13/2008	1.999	1.341	3.11	114,934
2/14/2008	1.489	0.983	3.15	85,593
2/15/2008	0.475	0.313	2.68	27,292
2/16/2008	0.038	0.024	2.28	2,170
2/17/2008	0.393	0.268	3.89	22,569
2/18/2008	0.815	0.536	3.75	46,826
2/19/2008	0.061	0.040	2.98	3,517
2/20/2008	0.000	0.000	2.51	0
2/21/2008	0.000	0.000	2.14	0

Montgomery Fork Measured Runoff Summary - CONTINUED

Date (mm/dd/yyyy)	Surface Runoff (mm)	Average Daily Runoff Discharge (cms)	Peak Discharge (cms)	Runoff (Mg or m3)
2/22/2008	0.165	0.112	2.14	9,486
2/23/2008	0.313	0.206	2.04	18,007
2/24/2008	0.000	0.000	1.64	0
2/25/2008	0.000	0.000	1.64	0
2/26/2008	0.651	0.441	2.75	37,441
2/27/2008	1.384	0.918	3.28	79,544
2/28/2008	0.931	0.618	3.52	53,518
2/29/2008	0.382	0.253	3.11	21,966
3/1/2008	0.997	0.666	3.62	57,316
3/2/2008	0.617	0.407	3.52	35,451
3/3/2008	0.034	0.021	3.08	1,949
3/4/2008	2.963	1.913	9.00	170,346
3/5/2008	1.987	1.332	6.16	114,246
3/6/2008	0.195	0.126	4.15	11,194
3/7/2008	1.770	1.195	5.39	101,771

Ligias Fork Measured Runoff Summary

Date (mm/dd/yyyy)	Surface Runoff (mm)	Average Daily Runoff Discharge (cms)	Peak Discharge (cms)	Runoff (Mg or m3)
7/19/2007	0.020	0.012	0.06	1,037
7/20/2007	0.027	0.016	0.04	1,411
7/21/2007	0.036	0.022	0.07	1,869
7/22/2007	0.025	0.015	0.07	1,330
7/23/2007	0.003	0.002	0.07	174
7/24/2007	0.013	0.008	0.07	697
7/25/2007	0.875	0.532	2.28	45,637
7/26/2007	0.253	0.150	0.62	13,222
7/27/2007	0.040	0.024	0.20	2,071
7/28/2007	6.487	3.921	14.63	338,514
7/29/2007	0.253	0.151	0.62	13,201
7/30/2007	0.221	0.133	0.38	11,547
7/31/2007	0.058	0.035	0.24	3,047
8/1/2007	0.002	0.001	0.17	112
8/2/2007	0.000	0.000	0.17	0
8/3/2007	0.017	0.011	0.38	861
8/4/2007	0.228	0.137	0.45	11,880
8/5/2007	0.161	0.097	0.36	8,414
8/6/2007	0.105	0.063	0.32	5,493
8/7/2007	0.003	0.002	0.19	163
8/8/2007	0.000	0.000	0.19	0
8/9/2007	0.000	0.000	0.16	0
8/10/2007	0.000	0.000	0.15	0
8/11/2007	0.000	0.000	0.14	0
8/12/2007	0.000	0.000	0.14	0
8/13/2007	0.000	0.000	0.13	0
8/14/2007	0.000	0.000	0.13	0
8/15/2007	0.000	0.000	0.13	0
8/16/2007	0.000	0.000	0.13	0
8/17/2007	0.000	0.000	0.13	0
8/18/2007	0.000	0.000	0.12	0
8/19/2007	0.000	0.000	0.12	0
8/20/2007	0.000	0.000	0.12	0
8/21/2007	0.000	0.000	0.13	0

Ligias Fork Measured Runoff Summary - CONTINUED				
Date (mm/dd/yyyy)	Surface Runoff (mm)	Average Daily Runoff Discharge (cms)	Peak Discharge (cms)	Runoff (Mg or m3)
8/22/2007	0.000	0.000	0.13	0
8/23/2007	0.000	0.000	0.13	0
8/24/2007	0.000	0.000	0.14	0
8/25/2007	0.000	0.000	0.14	0
8/26/2007	0.034	0.021	0.15	1,761
8/27/2007	0.066	0.040	0.15	3,450
8/28/2007	0.046	0.028	0.18	2,423
8/29/2007	0.055	0.033	0.18	2,891
8/30/2007	0.034	0.021	0.18	1,790
8/31/2007	0.032	0.019	0.18	1,647
9/1/2007	0.049	0.030	0.19	2,569
9/2/2007	0.050	0.030	0.19	2,607
9/3/2007	0.052	0.031	0.19	2,703
9/4/2007	0.059	0.035	0.19	3,060
9/5/2007	0.025	0.015	0.16	1,307
9/6/2007	0.004	0.003	0.16	235
9/7/2007	0.000	0.000	0.16	0
9/8/2007	0.000	0.000	0.16	0
9/9/2007	0.000	0.000	0.16	0
9/10/2007	0.000	0.000	0.17	0
9/11/2007	0.033	0.021	0.25	1,742
9/12/2007	0.118	0.071	0.28	6,162
9/13/2007	0.104	0.063	0.29	5,438
9/14/2007	0.111	0.067	0.28	5,773
9/15/2007	0.124	0.074	0.32	6,458
9/16/2007	0.002	0.001	0.18	116
9/17/2007	0.000	0.000	0.16	0
9/18/2007	0.000	0.000	0.15	0
9/19/2007	0.013	0.008	0.15	666
9/20/2007	0.006	0.003	0.15	303
9/21/2007	0.000	0.000	0.15	0
9/22/2007	0.000	0.000	0.14	0
9/23/2007	0.000	0.000	0.15	0
9/24/2007	0.000	0.000	0.15	0

Ligias Fork Measured Runoff Summary - CONTINUED				
		Average Daily		
	Surface	Runoff	Peak	
Date	Runoff	Discharge	Discharge	Runoff
(mm/dd/yyyy)	(mm)	(cms)	(cms)	(Mg or m3)
9/25/2007	0.000	0.000	0.15	0
9/26/2007	0.000	0.000	0.15	0
9/27/2007	0.000	0.000	0.14	0
9/28/2007	0.009	0.006	0.16	474
9/29/2007	0.009	0.005	0.16	477
9/30/2007	0.002	0.001	0.17	121
10/1/2007	0.000	0.000	0.18	0
10/2/2007	0.000	0.000	0.17	0
10/3/2007	0.000	0.000	0.17	0
10/4/2007	0.003	0.002	0.19	148
10/5/2007	0.053	0.032	0.19	2,741
10/6/2007	0.039	0.023	0.19	2,039
10/7/2007	0.001	0.000	0.15	34
10/8/2007	0.000	0.000	0.15	0
10/9/2007	0.000	0.000	0.15	0
10/10/2007	0.000	0.000	0.16	0
10/11/2007	0.000	0.000	0.17	0
10/12/2007	0.000	0.000	0.15	0
10/13/2007	0.000	0.000	0.14	0
10/14/2007	0.000	0.000	0.14	0
10/15/2007	0.000	0.000	0.14	0
10/16/2007	0.000	0.000	0.15	0
10/17/2007	0.000	0.000	0.15	0
10/18/2007	0.020	0.012	0.16	1,023
10/19/2007	0.041	0.025	0.03	2,136
10/20/2007	0.047	0.029	0.20	2,464
10/21/2007	0.050	0.030	0.19	2,611
10/22/2007	0.000	0.000	0.16	12
10/23/2007	0.578	0.369	3.10	30,183
10/24/2007	3.614	2.178	2.81	188,569
10/25/2007	2.707	1.628	2.30	141,267
10/26/2007	1.275	0.769	1.60	66,543
10/27/2007	0.888	0.530	1.40	46,316
10/28/2007	0.000	0.000	0.40	0

Ligias Fork Measured Runoff Summary - CONTINUED				
Date (mm/dd/yyyy)	Surface Runoff (mm)	Average Daily Runoff Discharge (cms)	Peak Discharge (cms)	Runoff (Mg or m3)
10/29/2007	0.000	0.000	0.35	0
10/30/2007	0.000	0.000	0.33	0
10/31/2007	0.000	0.000	0.32	0
11/1/2007	0.000	0.000	0.17	0
11/2/2007	0.000	0.000	0.17	0
11/3/2007	0.000	0.000	0.17	0
11/4/2007	0.000	0.000	0.17	0
11/5/2007	0.003	0.002	0.18	134
11/6/2007	0.076	0.047	0.26	3,977
11/7/2007	0.106	0.064	0.28	5,521
11/8/2007	0.062	0.037	0.27	3,218
11/9/2007	0.000	0.000	0.23	0
11/10/2007	0.000	0.000	0.18	0
11/11/2007	0.000	0.000	0.18	0
11/12/2007	0.000	0.000	0.17	0
11/13/2007	0.000	0.000	0.17	0
11/14/2007	0.001	0.001	0.17	70
11/15/2007	0.423	0.258	0.49	22,052
11/16/2007	0.421	0.253	0.57	21,957
11/17/2007	0.087	0.052	0.35	4,557
11/18/2007	0.000	0.000	0.28	0
11/19/2007	0.000	0.000	0.24	0
11/20/2007	0.000	0.000	0.22	0
11/21/2007	0.000	0.000	0.21	0
11/22/2007	0.063	0.038	0.28	3,270
11/23/2007	0.156	0.095	0.33	8,156
11/24/2007	0.141	0.085	0.35	7,382
11/25/2007	0.058	0.035	0.28	3,047
11/26/2007	15.851	9.685	17.79	827,098
11/27/2007	15.213	9.094	17.32	793,822
11/28/2007	2.681	1.602	3.38	139,870
11/29/2007	0.300	0.185	1.21	15,670
11/30/2007	0.700	0.403	1.07	36,501
12/1/2007	0.214	0.127	0.63	11,166

Ligias Fork Measured Runoff Summary - CONTINUED				
Date (mm/dd/yyyy)	Surface Runoff (mm)	Average Daily Runoff Discharge (cms)	Peak Discharge (cms)	Runoff (Mg or m3)
12/2/2007	0.000	0.000	0.33	0
12/3/2007	0.183	0.112	0.53	9,540
12/4/2007	0.216	0.130	0.54	11,295
12/5/2007	0.202	0.122	0.47	10,549
12/6/2007	0.226	0.136	0.53	11,796
12/7/2007	0.035	0.021	0.42	1,846
12/8/2007	0.000	0.000	0.36	0
12/9/2007	0.000	0.000	0.35	0
12/10/2007	0.000	0.000	0.31	0
12/11/2007	0.000	0.000	0.27	0
12/12/2007	0.000	0.000	0.22	0
12/13/2007	0.050	0.031	0.29	2,617
12/14/2007	0.144	0.087	0.32	7,503
12/15/2007	0.090	0.053	0.32	4,684
12/16/2007	0.138	0.085	0.42	7,224
12/17/2007	0.224	0.135	0.45	11,667
12/18/2007	0.252	0.151	0.48	13,159
12/19/2007	0.136	0.082	0.37	7,088
12/20/2007	0.063	0.038	0.36	3,300
12/21/2007	0.000	0.000	0.29	0
12/22/2007	0.000	0.000	0.32	0
12/23/2007	0.590	0.361	1.64	30,788
12/24/2007	0.638	0.382	1.11	33,312
12/25/2007	0.113	0.067	0.68	5,872
12/26/2007	0.000	0.000	0.84	0
12/27/2007	0.000	0.000	0.54	0
12/28/2007	2.245	1.406	7.59	117,148
12/29/2007	6.861	4.102	9.23	358,015
12/30/2007	0.966	0.575	3.34	50,386
12/31/2007	0.006	0.003	2.64	293
1/1/2008	0.000	0.000	2.42	0
1/2/2008	0.000	0.000	4.78	0
1/3/2008	0.000	0.000	7.01	0
1/4/2008	0.000	0.000	2.62	0

Ligias Fork Measured Runoff Summary - CONTINUED				
		Average Daily		
	Surface	Runoff	Peak	
Date	Runoff	Discharge	Discharge	Runoff
(mm/dd/yyyy)	(mm)	(cms)	(cms)	(Mg or m3)
1/5/2008	0.000	0.000	0.50	0
1/6/2008	0.000	0.000	0.49	0
1/7/2008	0.000	0.000	0.47	0
1/8/2008	0.002	0.002	0.37	119
1/9/2008	1.027	0.623	2.11	53,573
1/10/2008	15.523	9.750	58.59	810,011
1/11/2008	37.181	22.102	56.24	1,940,098
1/12/2008	1.351	0.791	5.95	70,490
1/13/2008	0.000	0.000	2.42	0
1/14/2008	0.254	0.154	1.78	13,247
1/15/2008	0.059	0.034	1.29	3,071
1/16/2008	0.000	0.000	0.98	0
1/17/2008	0.000	0.000	0.84	0
1/18/2008	0.000	0.000	0.92	0
1/19/2008	0.000	0.000	0.72	0
1/20/2008	0.000	0.000	0.66	0
1/21/2008	0.000	0.000	0.64	0
1/22/2008	0.025	0.015	0.59	1,289
1/23/2008	0.040	0.024	0.72	2,109
1/24/2008	0.000	0.000	0.64	0
1/25/2008	0.000	0.000	0.68	0
1/26/2008	0.000	0.000	0.60	0
1/27/2008	0.000	0.000	0.60	0
1/28/2008	0.000	0.000	0.58	0
1/29/2008	0.010	0.007	0.76	496
1/30/2008	0.982	0.593	1.82	51,236
1/31/2008	0.171	0.102	0.92	8,943
2/1/2008	1.347	0.820	2.95	70,281
2/2/2008	0.941	0.564	2.58	49,120
2/3/2008	0.137	0.081	1.97	7,139
2/4/2008	9.442	5.825	22.72	492,695
2/5/2008	16.492	9.866	19.08	860,530
2/6/2008	20.962	12.701	27.29	1,093,822
2/7/2008	4.830	2.849	12.75	252,035

Ligias Fork Measured Runoff Summary - CONTINUED				
		Average Daily		
	Surface	Runoff	Peak	
Date	Runoff	Discharge	Discharge	Runoff
(mm/dd/yyyy)	(mm)	(cms)	(cms)	(Mg or m3)
2/8/2008	0.021	0.011	3.12	1,079
2/9/2008	0.000	0.000	2.07	0
2/10/2008	0.000	0.000	1.54	0
2/11/2008	0.000	0.000	1.151	0
2/12/2008	0.027	0.017	0.96	1,407
2/13/2008	1.511	0.920	2.05	78,827
2/14/2008	1.177	0.710	2.05	61,408
2/15/2008	0.770	0.459	1.93	40,159
2/16/2008	0.155	0.093	0.82	8,101
2/17/2008	0.390	0.243	2.91	20,363
2/18/2008	1.026	0.615	2.75	53,552
2/19/2008	0.192	0.114	2.05	10,000
2/20/2008	0.000	0.000	1.62	0
2/21/2008	0.000	0.000	1.31	0
2/22/2008	0.033	0.021	1.11	1,700
2/23/2008	0.476	0.289	1.50	24,853
2/24/2008	0.291	0.173	1.76	15,205
2/25/2008	0.000	0.000	1.40	0
2/26/2008	0.523	0.322	1.64	27,280
2/27/2008	1.760	1.066	2.07	91,828
2/28/2008	1.512	0.912	2.23	78,874
2/29/2008	1.167	0.707	2.93	60,890
3/1/2008	2.496	1.505	3.63	130,257
3/2/2008	1.031	0.617	3.01	53,774
3/3/2008	0.123	0.072	2.23	6,424
3/4/2008	27.699	16.897	50.73	1,445,346
3/5/2008	19.256	11.496	26.12	1,004,761
3/6/2008	2.438	1.417	7.36	127,204
3/7/2008	3.532	2.142	7.83	184,316

Date (mm/dd/yyyy)	Surface Runoff (mm)	Average Daily Runoff Discharge (cms)	Peak Discharge (cms)	Runoff (Mg or m3)
11/2/2007	0.000	0.000	0.01	0
11/3/2007	0.000	0.000	0.06	0
11/4/2007	0.000	0.000	0.10	0
11/5/2007	0.009	0.009	0.26	676
11/6/2007	0.267	0.225	0.79	19,501
11/7/2007	0.034	0.028	0.27	2,472
11/8/2007	0.002	0.002	0.18	142
11/9/2007	0.000	0.000	0.18	0
11/10/2007	0.000	0.000	0.15	0
11/11/2007	0.000	0.000	0.13	0
11/12/2007	0.000	0.000	0.11	0
11/13/2007	0.204	0.176	0.54	14,930
11/14/2007	0.262	0.223	1.18	19,105
11/15/2007	1.403	1.186	2.47	102,414
11/16/2007	0.374	0.312	1.11	27,281
11/17/2007	0.003	0.002	0.52	193
11/18/2007	0.000	0.000	0.43	0
11/19/2007	0.000	0.000	0.33	0
11/20/2007	0.000	0.000	0.30	0
11/21/2007	0.012	0.011	0.28	898
11/22/2007	0.082	0.069	0.33	5,959
11/23/2007	0.049	0.041	0.34	3,610
11/24/2007	0.010	0.008	0.30	714
11/25/2007	0.000	0.000	0.29	0
11/26/2007	9.630	8.190	21.18	703,158
11/27/2007	3.037	2.515	9.82	221,765
11/28/2007	0.000	0.000	2.44	0
11/29/2007	0.000	0.000	1.46	0
11/30/2007	0.000	0.000	0.98	0
12/1/2007	0.000	0.000	0.61	0
12/2/2007	0.000	0.000	0.52	0
12/3/2007	0.354	0.299	1.16	25,835
12/4/2007	0.024	0.021	0.40	1,786
12/5/2007	0.003	0.002	0.37	203

Smokey Creek Measured Runoff Summary - CONTINUED

Date (mm/dd/yyyy)	Surface Runoff (mm)	Average Daily Runoff Discharge (cms)	Peak Discharge (cms)	Runoff (Mg or m3)
12/6/2007	0.000	0.000	0.34	0
12/7/2007	0.000	0.000	0.33	0
12/8/2007	0.080	0.068	0.26	5,874
12/9/2007	0.052	0.044	0.26	3,828
12/10/2007	0.001	0.001	0.24	61
12/11/2007	0.000	0.000	0.22	0
12/12/2007	0.021	0.018	0.26	1,531
12/13/2007	0.080	0.068	0.33	5,855
12/14/2007	0.047	0.039	0.35	3,402
12/15/2007	0.020	0.017	0.37	1,441
12/16/2007	0.412	0.349	0.93	30,053
12/17/2007	0.242	0.203	0.84	17,669
12/18/2007	0.033	0.027	0.70	2,379
12/19/2007	0.000	0.000	0.59	0
12/20/2007	0.000	0.000	0.43	0
12/21/2007	0.033	0.028	0.38	2,401
12/22/2007	0.020	0.017	0.33	1,441
12/23/2007	1.020	0.869	2.42	74,449
12/24/2007	0.881	0.739	2.35	64,339
12/25/2007	0.105	0.087	1.55	7,700
12/26/2007	0.000	0.000	1.28	0
12/27/2007	0.000	0.000	1.11	0
12/28/2007	1.451	1.253	5.91	105,973
12/29/2007	2.510	2.100	5.83	183,255
12/30/2007	0.385	0.320	2.79	28,092
12/31/2007	0.000	0.000	2.01	0
1/1/2008	0.000	0.000	1.50	0
1/2/2008	0.000	0.000	1.07	0
1/3/2008	0.000	0.000	0.66	0
1/4/2008	0.000	0.000	0.47	0
1/5/2008	0.019	0.017	0.50	1,413
1/6/2008	0.144	0.122	0.54	10,533
1/7/2008	0.037	0.030	0.45	2,675
1/8/2008	0.003	0.003	0.52	195

Smokey Creek Measured Runoff Summary - CONTINUED

Date (mm/dd/yyyy)	Surface Runoff (mm)	Average Daily Runoff Discharge (cms)	Peak Discharge (cms)	Runoff (Mg or m3)
1/9/2008	4.561	3.874	7.79	333,031
1/10/2008	10.511	9.069	44.34	767,427
1/11/2008	14.127	11.781	31.95	1,031,493
1/12/2008	6.396	5.378	10.60	467,002
1/13/2008	2.008	1.676	6.61	146,583
1/14/2008	0.172	0.143	3.76	12,548
1/15/2008	0.000	0.000	3.34	0
1/16/2008	0.001	0.001	2.88	41
1/17/2008	0.185	0.158	1.02	13,544
1/18/2008	0.055	0.046	0.91	4,043
1/19/2008	0.000	0.000	0.75	0
1/20/2008	0.000	0.000	0.66	0
1/21/2008	0.097	0.083	0.61	7,098
1/22/2008	0.292	0.249	0.77	21,354
1/23/2008	0.435	0.368	0.86	31,778
1/24/2008	0.404	0.341	0.75	29,516
1/25/2008	0.164	0.138	0.63	12,001
1/26/2008	0.095	0.081	0.54	6,972
1/27/2008	0.031	0.025	0.52	2,241
1/28/2008	0.000	0.000	0.45	0
1/29/2008	0.049	0.043	0.70	3,544
1/30/2008	0.432	0.365	0.91	31,572
1/31/2008	0.202	0.170	0.66	14,743
2/1/2008	1.232	1.050	2.10	89,942
2/2/2008	1.561	1.318	1.99	113,992
2/3/2008	1.254	1.058	1.78	91,551
2/4/2008	1.806	1.539	4.11	131,852
2/5/2008	2.967	2.502	3.64	216,613
2/6/2008	9.216	7.832	18.94	672,937
2/7/2008	5.855	4.907	9.86	427,508
2/8/2008	2.200	1.852	4.03	160,624
2/9/2008	1.221	1.027	2.99	89,131
2/10/2008	0.439	0.361	2.31	32,053
2/11/2008	0.000	0.000	1.53	0

Smokey Creek Measured Runoff Summary - CONTINUED				
Date (mm/dd/yyyy)	Surface Runoff (mm)	Average Daily Runoff Discharge (cms)	Peak Discharge (cms)	Runoff (Mg or m3)
2/12/2008	0.021	0.029	1.28	1,554
2/13/2008	1.664	1.409	3.91	121,472
2/14/2008	0.625	0.524	3.22	45,624
2/15/2008	0.081	0.067	2.65	5,940
2/16/2008	0.000	0.000	2.15	0
2/17/2008	0.906	0.781	5.21	66,159
2/18/2008	1.550	1.299	4.70	113,184
2/19/2008	0.378	0.316	3.11	27,611
2/20/2008	0.005	0.004	2.56	371
2/21/2008	0.000	0.000	2.08	0
2/22/2008	0.118	0.100	1.96	8,594
2/23/2008	0.001	0.001	1.69	69
2/24/2008	0.000	0.000	1.32	0
2/25/2008	0.000	0.000	1.16	0
2/26/2008	1.160	0.990	2.70	84,662
2/27/2008	1.399	1.180	2.74	102,125
2/28/2008	0.949	0.799	2.81	69,289
2/29/2008	2.522	2.174	9.74	184,168
3/1/2008	6.295	5.293	9.90	459,625
3/2/2008	1.655	1.383	5.75	120,849
3/3/2008	0.284	0.235	3.64	20,736
3/4/2008	6.875	5.863	12.63	501,988
3/5/2008	6.141	5.154	11.19	448,382
3/6/2008	0.961	0.795	6.07	70,170
3/7/2008	4.131	3.535	10.48	301,652

Appendix E

Measured Total Solids Data

Brimstone Creek Total Solids Analysis

Sample No. (---)	Sample Date (mm/dd/yyyy)	Time (hh:mm)	Total Suspended Solids (mg/L)	Total Dissolved Solids (mg/L)	Total Solids (mg/L)	Percent Dissolved (%)
BRIM-1	1/10/2008	3:30 PM	73	31	104	30%
BRIM-GRAB	1/10/2008	3:30 PM	84	36	120	30%
BRIM-1	1/11/2008	9:15 AM	48	48	96	50%
BRIM-2	1/11/2008	9:15 AM	44	44	88	50%
BRIM-3	1/11/2008	9:15 AM	61	61	122	50%
BRIM-GRAB	1/11/2008	9:15 AM	68	68	136	50%
BRIM-BLANK	1/26/2008	12:30 PM	0	24	24	100%
BRIM-1	1/29/2008	1:00 PM	3	15	18	83%
BRIM-2	1/29/2008	1:00 PM	5	34	39	87%
BRIM-3	1/29/2008	1:00 PM	1	9	10	90%
BRIM-GRAB	1/29/2008	1:00 PM	5	39	44	89%
BRIM-1	1/30/2008	8:00 AM	4	20	24	85%
BRIM-2	1/30/2008	8:00 AM	9	49	58	85%
BRIM-GRAB	1/30/2008	8:00 AM	5	31	36	85%
BRIM-2	2/1/2008	7:30 AM	9	27	36	75%
BRIM-3	2/1/2008	7:30 AM	8	24	32	75%
BRIM-GRAB	2/1/2008	7:30 AM	9	27	36	75%
BRIM-1	2/6/2008	9:30 AM	88	40	128	31%
BRIM-2	2/6/2008	9:30 AM	92	75	167	45%
BRIM-GRAB	2/6/2008	9:30 AM	82	15	110	14%
BRIM-ISCO	2/12/2008	3:00 AM	6	47	53	89%
BRIM-Grab	2/12/2008	10:00 AM	10	87	97	90%
BRIM-2	2/13/2008	2:00 PM	4	7	11	65%
BRIM-3	2/13/2008	2:00 PM	8	55	63	87%
BRIM -Grab	2/21/2008	11:00 AM	8	130	138	94%
BRIM-2	2/22/2008	9:15 AM	8	102	110	93%
BRIM-1	2/22/2008	9:15 AM	14	52	66	79%
BRIM-1	3/4/2008	11:00 AM	26	55	81	68%
BRIM-ISCO	3/4/2008	11:00 AM	130	40	170	24%

Montgomery Fork Total Solids Analysis

Sample No. (---)	Sample Date (mm/dd/yyyy)	Time (hh:mm)	Total Suspended Solids (mg/L)	Total Dissolved Solids (mg/L)	Total Solids (mg/L)	Percent Dissolved (%)
MF-1	1/10/2008	2:00 PM	187	21	208	10%
MF-2	1/10/2008	2:00 PM	119	13	132	10%
MF-3	1/10/2008	2:00 PM	135	15	150	10%
MF-Grab	1/10/2008	2:00 PM	211	23	234	10%
MF-1	1/11/2008	12:00 PM	59	59	118	50%
MF-2	1/11/2008	12:00 PM	38	38	76	50%
MF-3	1/11/2008	12:00 PM	35	35	70	50%
MF-Grab	1/11/2008	12:00 PM	6	6	12	50%
MF-BLANK	1/26/2008	2:00 PM	1	163	164	99%
MF-2	1/30/2008	9:30 AM	12	220	232	95%
MF-1	1/30/2008	9:30 AM	8	144	152	95%
MF-Grab	1/30/2008	9:30 AM	8	375	383	98%
MF-1	2/1/2008	9:30 AM	108	72	180	40%
MF-3	2/1/2008	9:30 AM	138	92	230	40%
MF-Grab	2/1/2008	9:30 AM	98	66	164	40%
MF-1	2/6/2008	10:45 AM	518	117	635	18%
MF-2	2/6/2008	10:45 AM	596	208	804	26%
MF-Grab	2/6/2008	10:45 AM	578	215	793	27%
MF-Grab	2/12/2008	4:00 PM	10	263	273	96%
MF-ISCO	2/13/2008	1:44 AM	66	200	266	75%
MF-1	2/13/2008	10:30 AM	12	72	84	86%
MF-3	2/13/2008	10:30 AM	18	195	213	92%
MF-Grab	2/21/2008	12:00 PM	26	222	248	90%
MF-1	2/22/2008	10:30 AM	50	210	260	81%
MF-2	2/22/2008	10:30 AM	48	525	573	92%
MF-ISCO	3/4/2008	7:30 AM	142	152	294	52%
MF-ROAD	2/1/2008	9:30 AM	440	90	530	17%
MF-ROAD	2/6/2008	11:00 AM	250	292	542	54%
MF-ROAD	2/22/2008	10:45 AM	1220	115	1335	9%
MF-ROAD	3/4/2008	9:45 AM	358	58	416	14%

Ligias Fork Total Solids Analysis

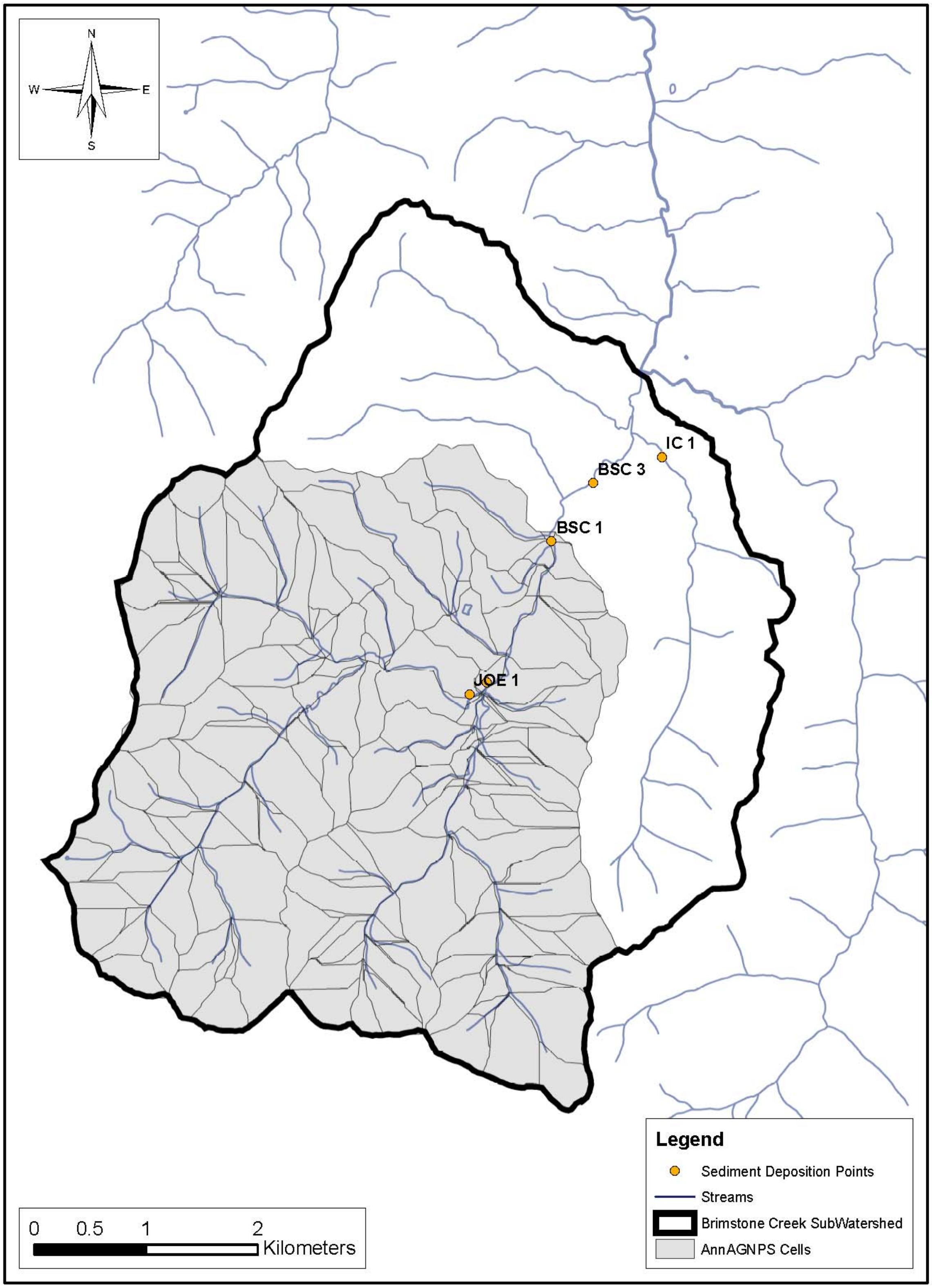
Sample No. (---)	Sample Date (mm/dd/yyyy)	Time (hh:mm)	Total Suspended Solids (mg/L)	Total Dissolved Solids (mg/L)	Total Solids (mg/L)	Percent Dissolved (%)
LF-1	1/10/2008	12:00 PM	88	10	98	10%
LF-2	1/10/2008	12:00 PM	18	2	20	10%
LF-3	1/10/2008	12:00 PM	43	5	48	10%
LF-Grab	1/10/2008	12:00 PM	83	9	92	10%
LF-1	1/11/2008	4:00 PM	33	33	66	50%
LF-2	1/11/2008	4:00 PM	9	9	18	50%
LF-3	1/11/2008	4:00 PM	35	35	70	50%
LF-Grab	1/11/2008	4:00 PM	52	52	104	50%
LF-1	1/30/2008	12:00 PM	14	130	144	90%
LF-2	1/30/2008	12:00 PM	19	171	190	90%
LF-Grab	1/30/2008	8:00 AM	19	169	188	90%
LF-3	2/1/2008	11:00 AM	277.2	185	462	40%
LF-3A	2/1/2008	11:00 AM	254.4	170	424	40%
LF-Grab	2/1/2008	11:00 AM	224.4	150	374	40%
LF-ISCO-1	2/1/2008	1:58 AM	105.0	245	350	70%
LF-ISCO-2	2/1/2008	12:58 PM	106.8	249	356	70%
LF-1	2/6/2008	12:30 PM	272	123	394.5	31%
LF-2	2/6/2008	12:30 PM	412	157	569.5	28%
LF-Grab	2/12/2008	1:00 PM	28	167	195	86%
LF-ISCO	2/13/2008	1:00 AM	454	173	627	28%
LF-Grab	2/21/2008	2:00 PM	16	235	251	94%
LF-2	2/22/2008	1:00 PM	28	140	168	83%
LF-1	2/22/2008	1:00 PM	8	25	33	76%
LF-2	3/4/2008	8:00 AM	240	152	392	39%
LF-3	3/4/2008	8:00 AM	220.0	143	363	39%
LF-ROAD	2/6/2008	12:30 PM	58	82	140.5	59%
LF-ROAD	3/4/2008	8:00 AM	712	55	767	7%

Smokey Creek Total Solids Analysis

Sample No. (---)	Sample Date (mm/dd/yyyy)	Time (hh:mm)	Total Suspended Solids (mg/L)	Total Dissolved Solids (mg/L)	Total Solids (mg/L)	Percent Dissolved (%)
SC-1	1/10/2008	12:45 PM	162	18	180	10%
SC-2	1/10/2008	12:45 PM	187	20.8	208	10%
SC-3	1/10/2008	12:45 PM	155	17.2	172	10%
SC-Grab	1/10/2008	12:45 PM	97	10.8	108	10%
SC-1	1/11/2008	2:00 PM	37	37	74	50%
SC-2	1/11/2008	2:00 PM	18	18	36	50%
SC-3	1/11/2008	2:00 PM	232	232	464	50%
SC-Grab	1/11/2008	1:00 PM	250	250	500	50%
SC-BLANK	1/26/2008	3:00 PM	1	71	72	99%
SC-2	1/30/2008	10:30 AM	28.5	161.5	190	85%
SC-1	1/30/2008	10:30 AM	30	170	200	85%
SC-Grab	1/30/2008	10:30 AM	37.5	212.5	250	85%
SC-2	2/1/2008	10:15 AM	114	76	190	40%
SC-3	2/1/2008	10:15 AM	116.4	77.6	194	40%
SC-Grab	2/1/2008	10:15 AM	122.4	81.6	204	40%
SC-1	2/6/2008	11:30 AM	450	195	645	30%
SC-2	2/6/2008	11:30 AM	648	140	788	18%
SC-Grab	2/6/2008	11:30 AM	614	82	696	12%
SC-Grab	2/12/2008	2:00 PM	8	245	253	97%
SC-ISCO	2/13/2008	4:38 AM	28	163	191	85%
SC-2	2/13/2008	11:15 AM	24	65	89	73%
SC-3	2/13/2008	11:15 AM	14	143	157	91%
SC-Grab	2/21/2008	12:45 PM	6	35	41	85%
SC-2	2/22/2008	11:00 AM	6	290	296	98%
SC-1	2/22/2008	11:00 AM	10	205	215	95%
SC-2	3/4/2008	9:00 AM	148	117	265	44%
SC-1	3/4/2008	9:00 AM	138	115	253	45%
SC-ROAD	2/22/2008	11:00 AM	48	37	85	44%

Appendix F

AnnAGNPS Flow Cell Generation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S
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BSC 3
BSC 1
JOE 1
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Sediment Deposition Points
Streams
Brimstone Creek SubWatershed
AnnAGNPS Cells
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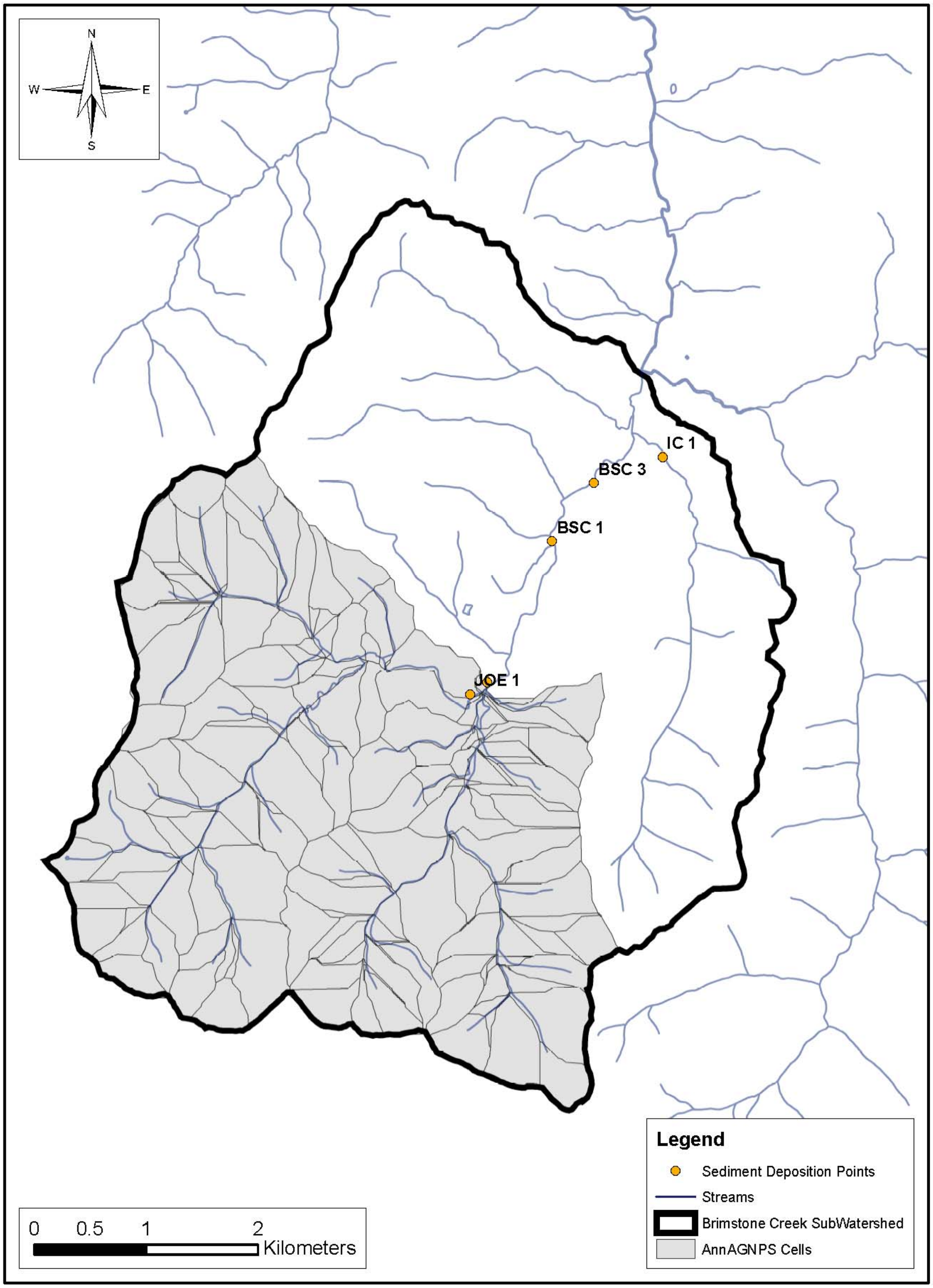
1
2
Kilometers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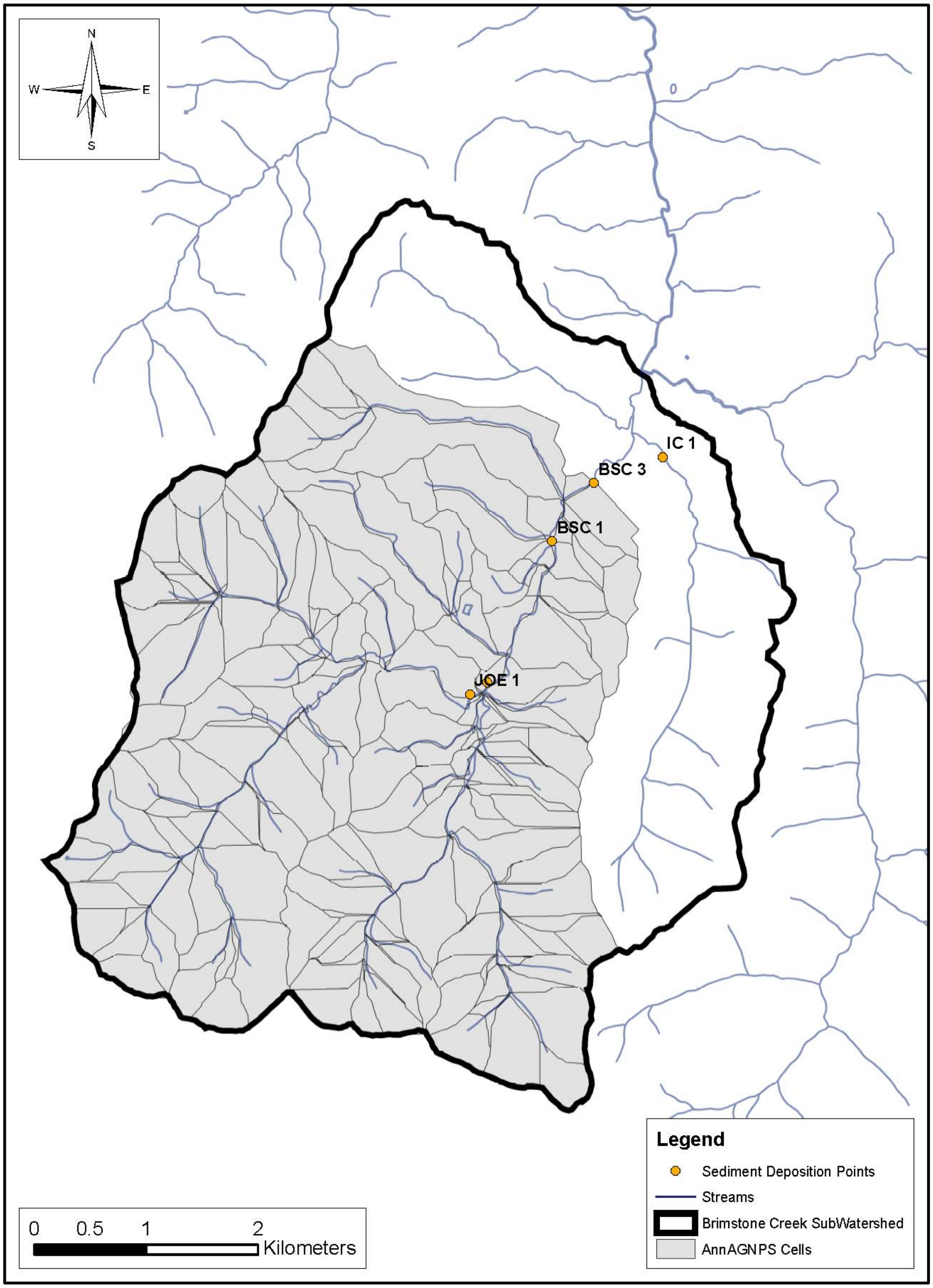
Brimstone Creek SubWatershed
AnnAGNPS Cells
0 0.5 1 2
Kilometers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IC 1
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Streams
Brimstone Creek SubWatershed
AnnAGNPS Cells
0
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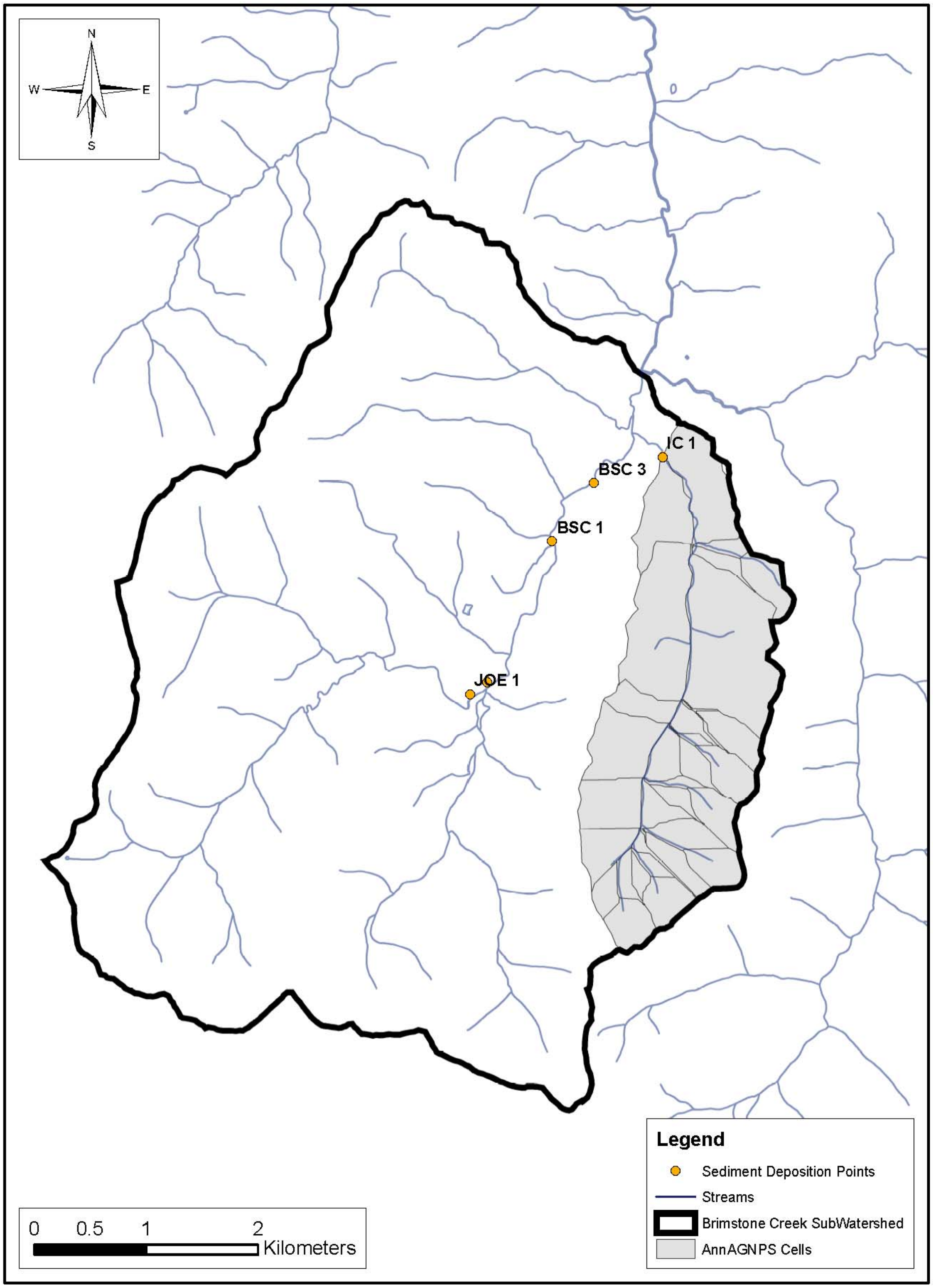
1
2
Kilometers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IC 1
BSC 3
BSC 1
JOE 1
Legend
Sediment Deposition Points
Streams
Brimstone Creek SubWatershed
AnnAGNPS Cells
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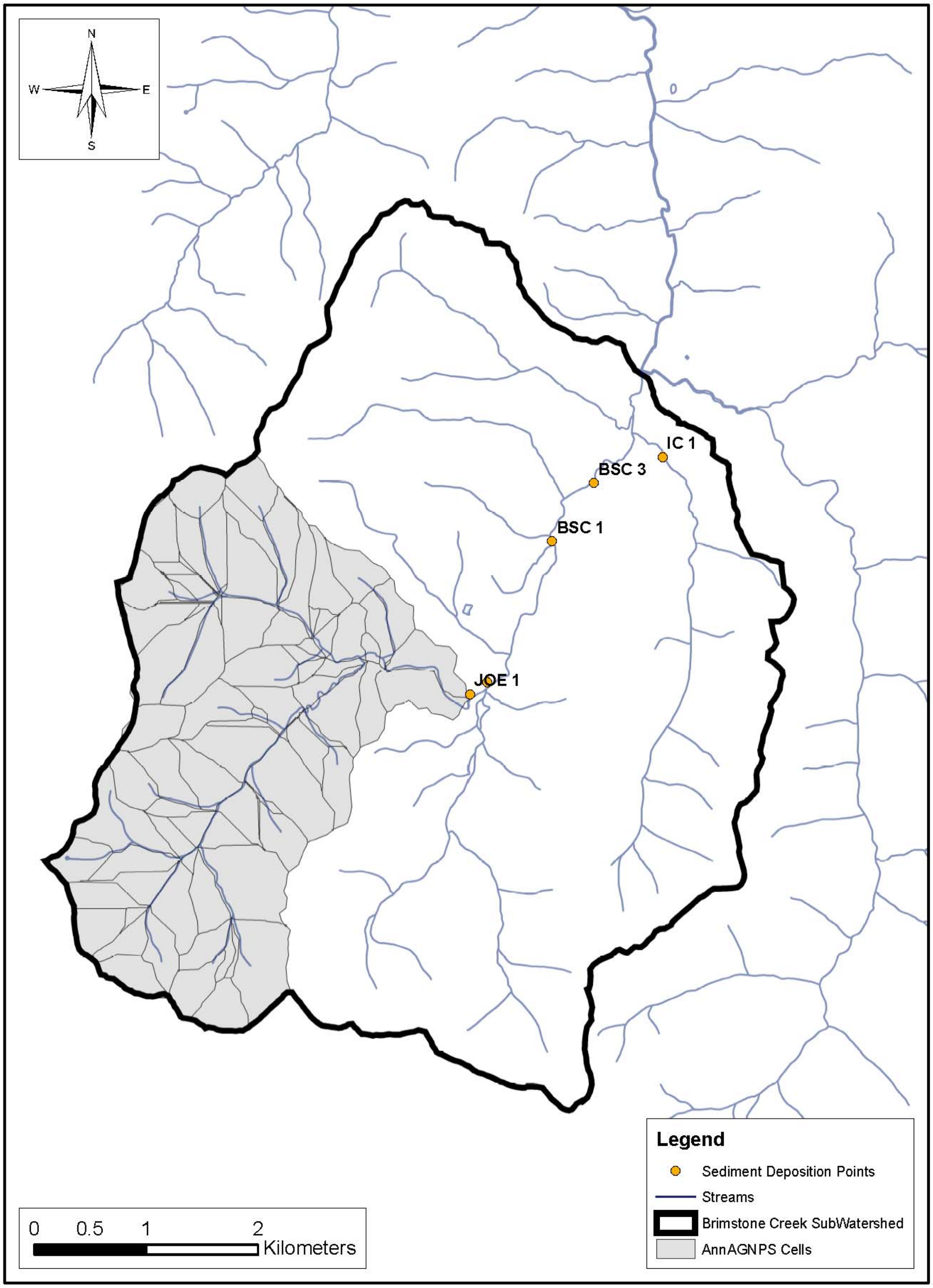
Kilometers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Sediment Deposition Points
Streams
Brimstone Creek SubWatershed
AnnAGNPS Cells
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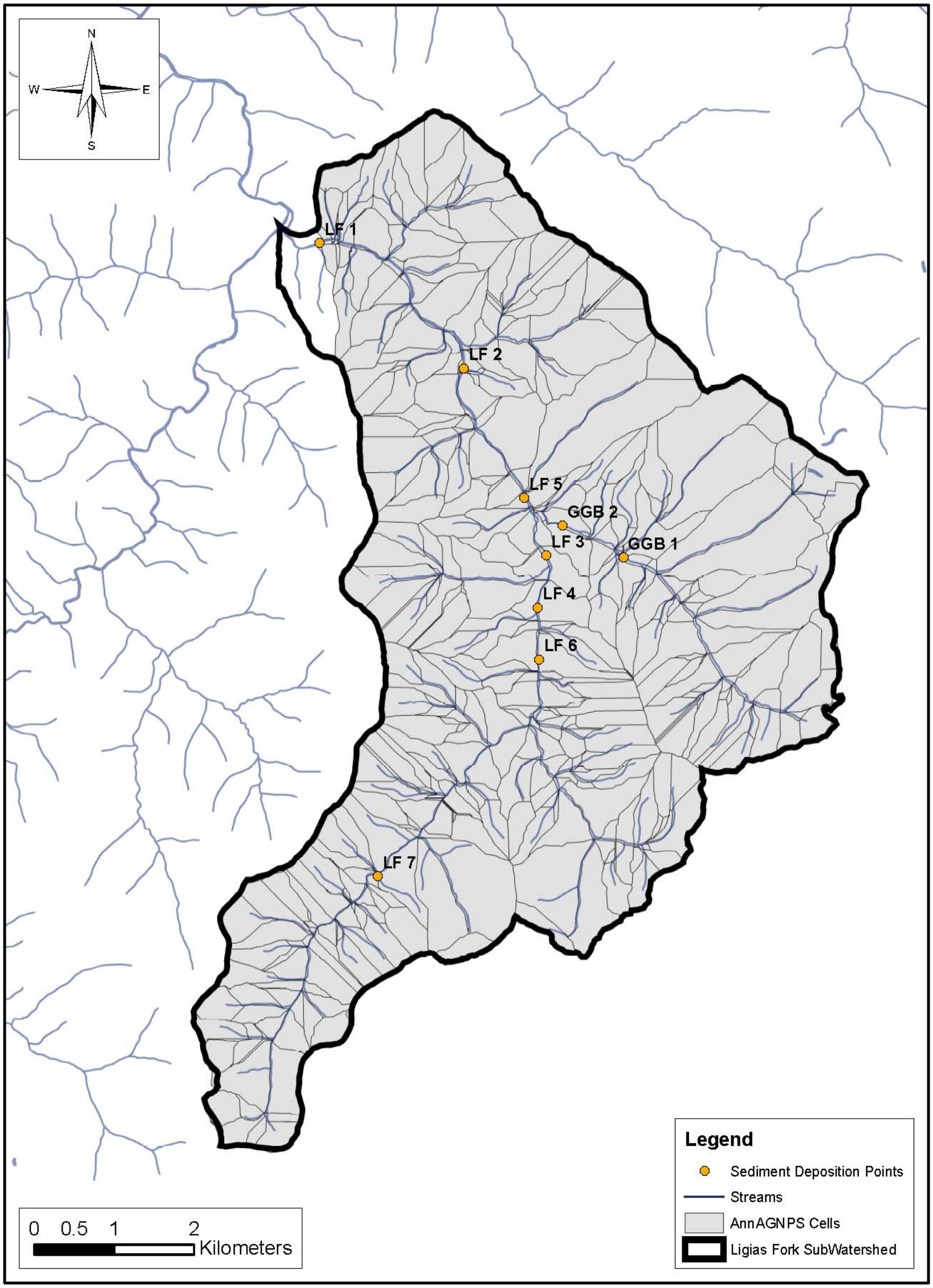
0.5
1
2
Kilometers



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LF 3
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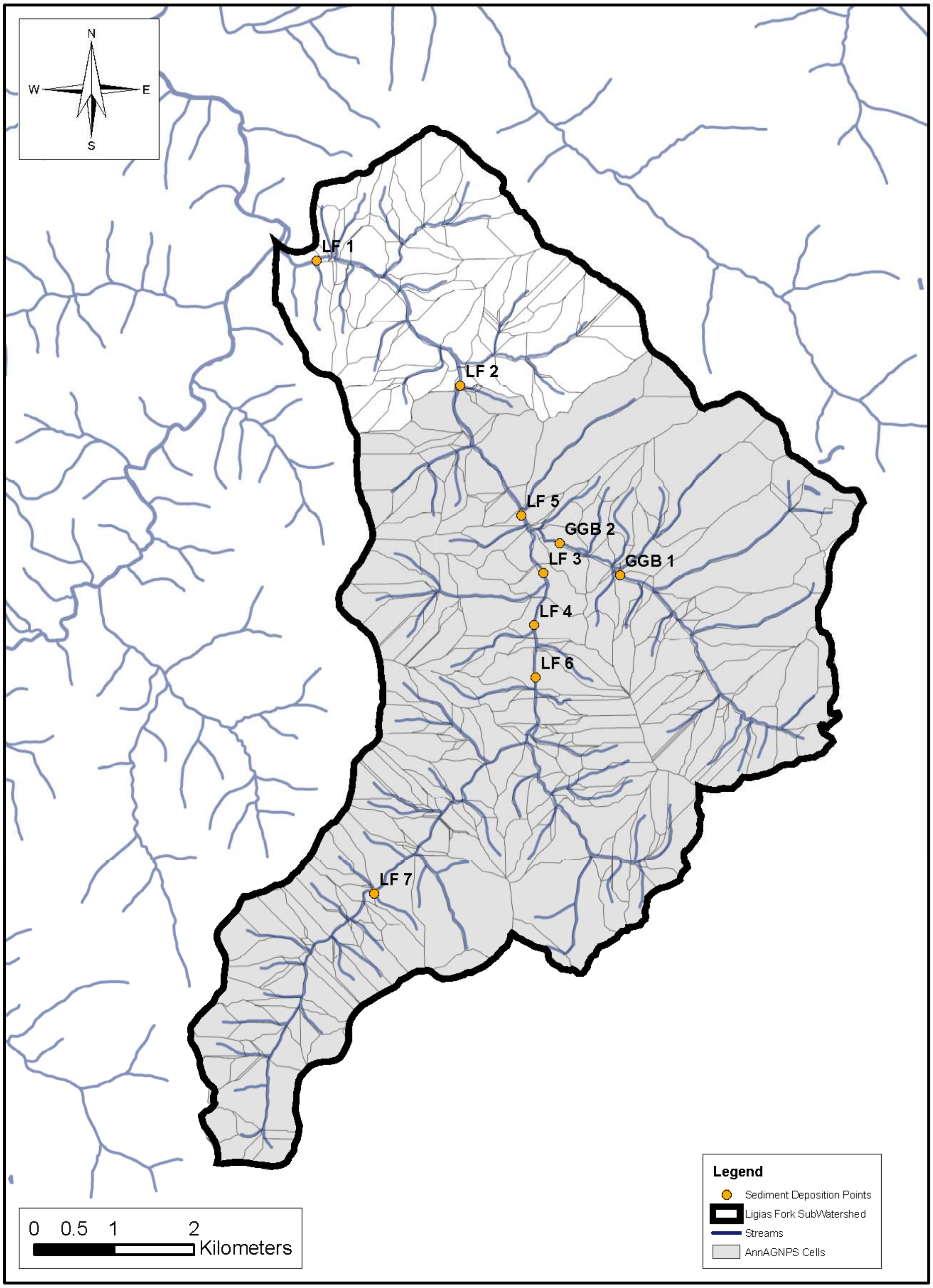
Kilometers
Legend
Sediment Deposition Points
Streams
AnnAGNPS Cells
Ligias Fork SubWatershed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Streams
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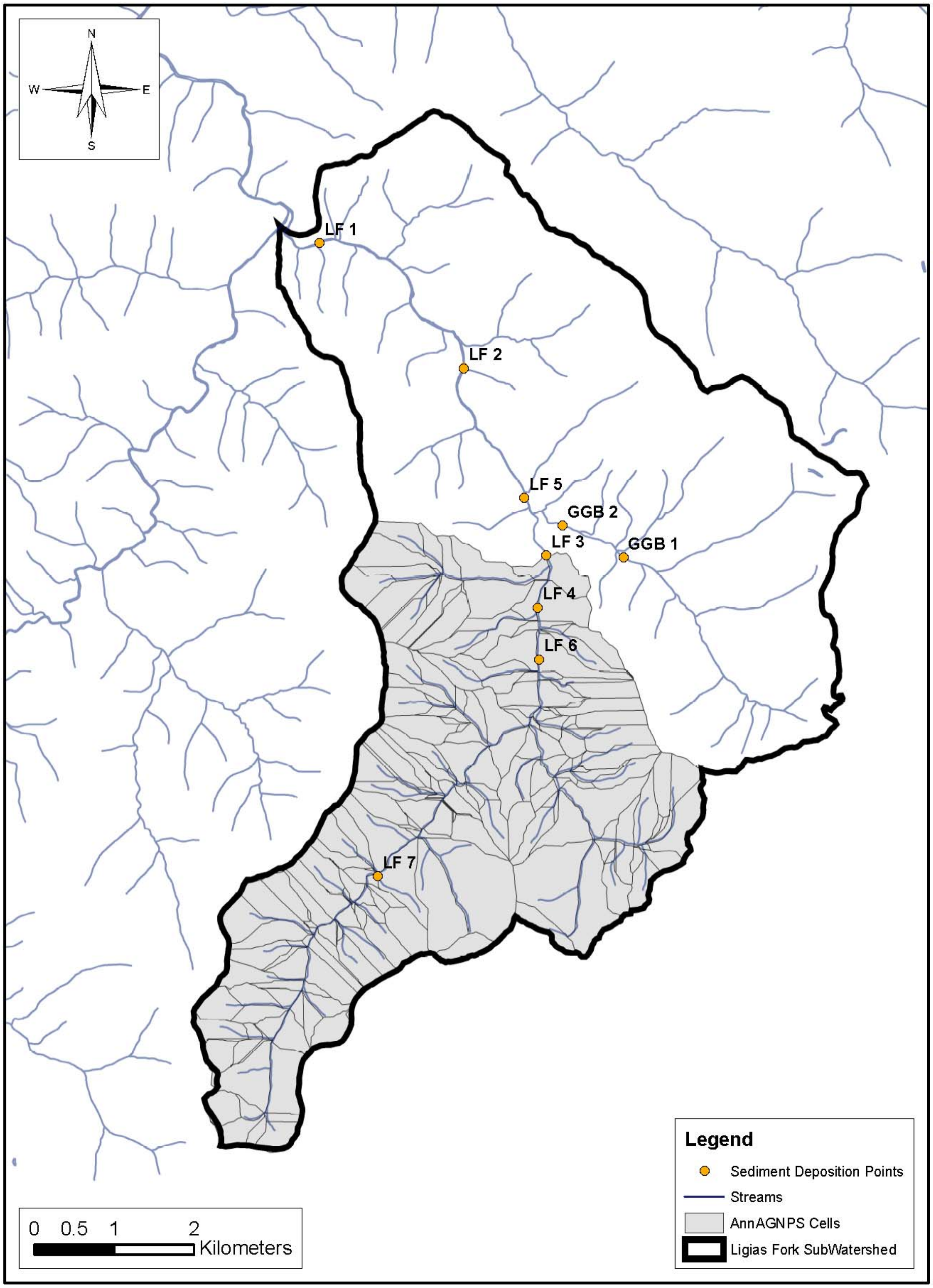
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Streams
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Ligias Fork SubWatershed
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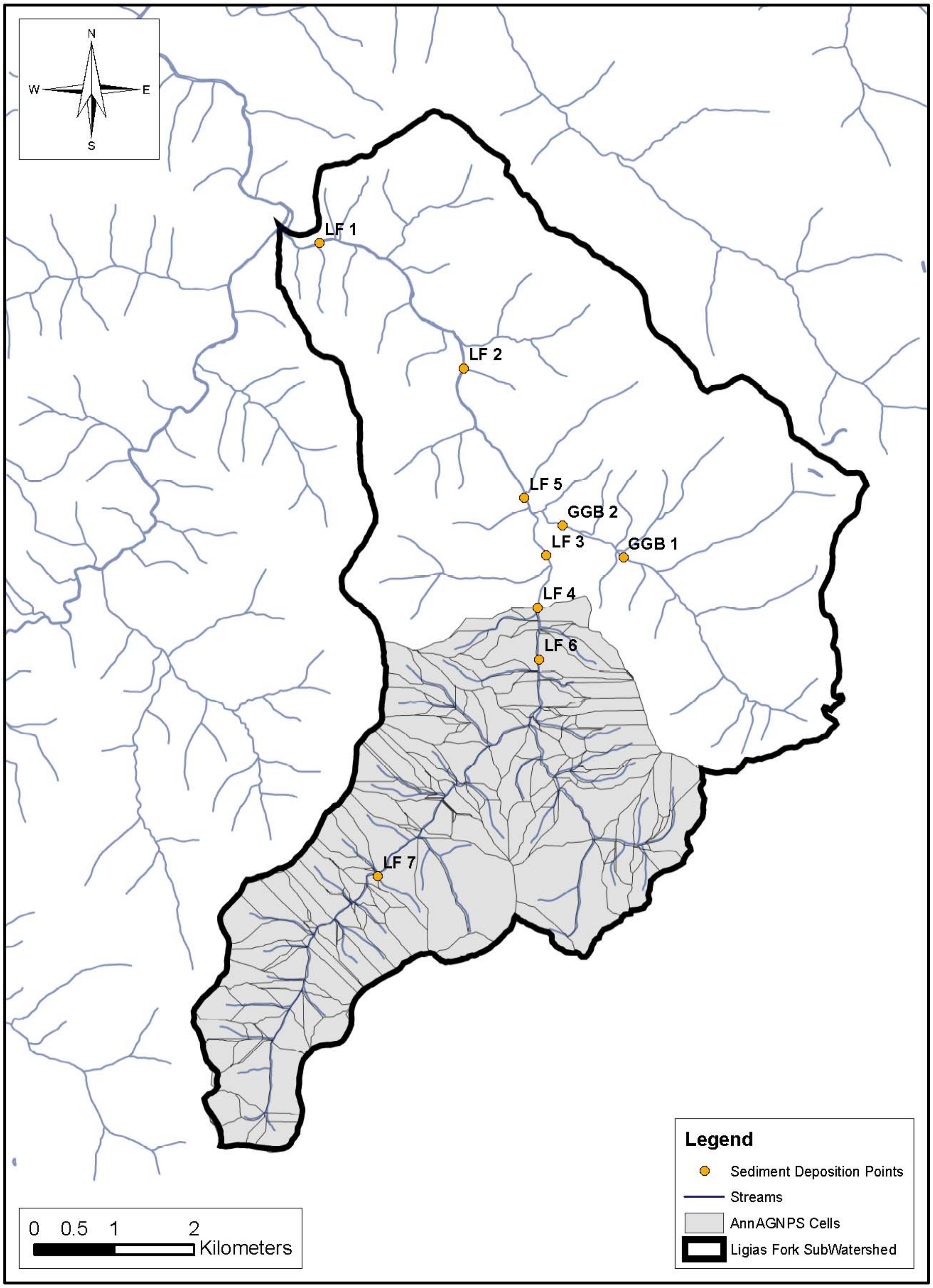
Kilometers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Ligias Fork SubWatershed
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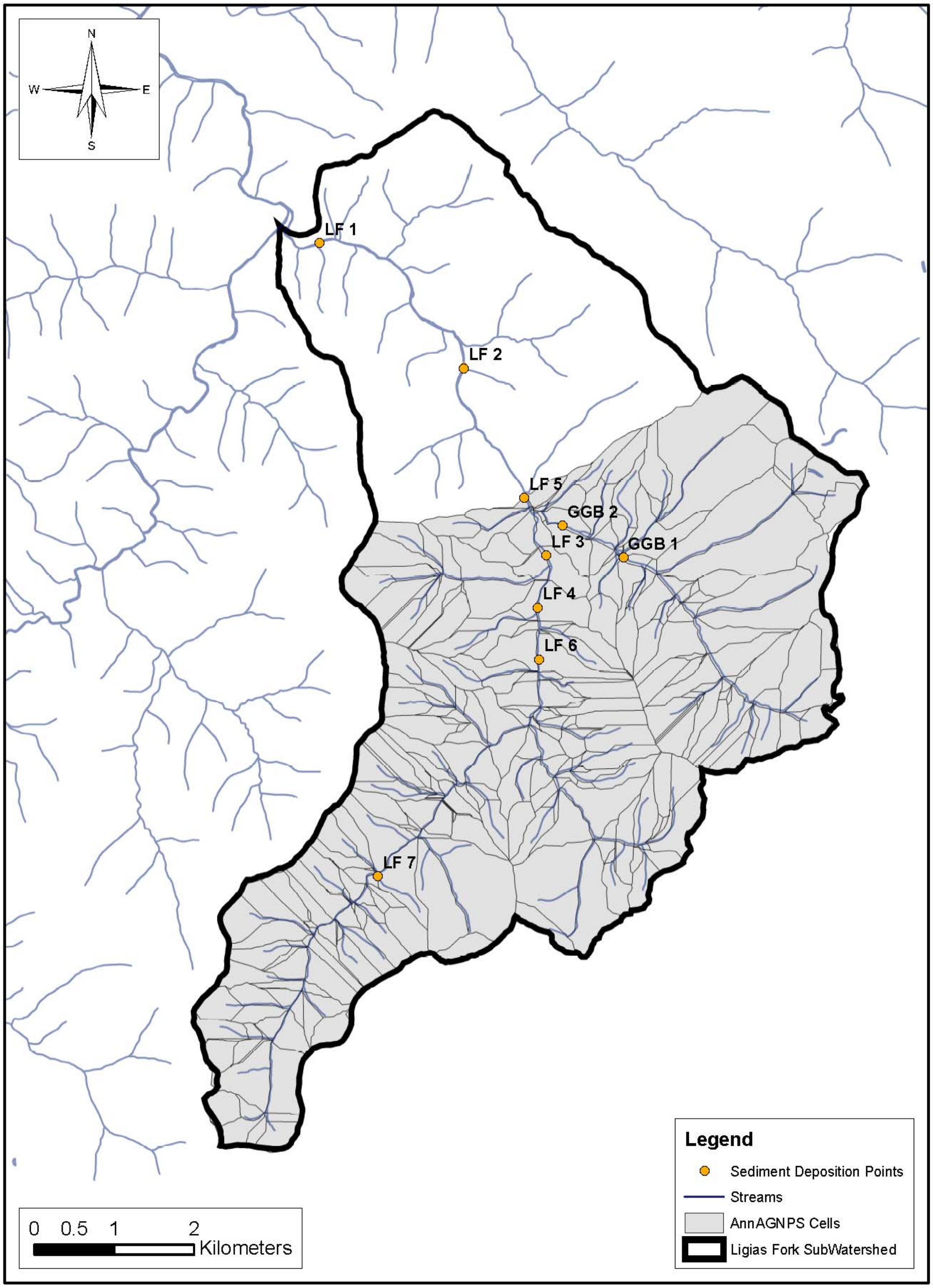
Kilometers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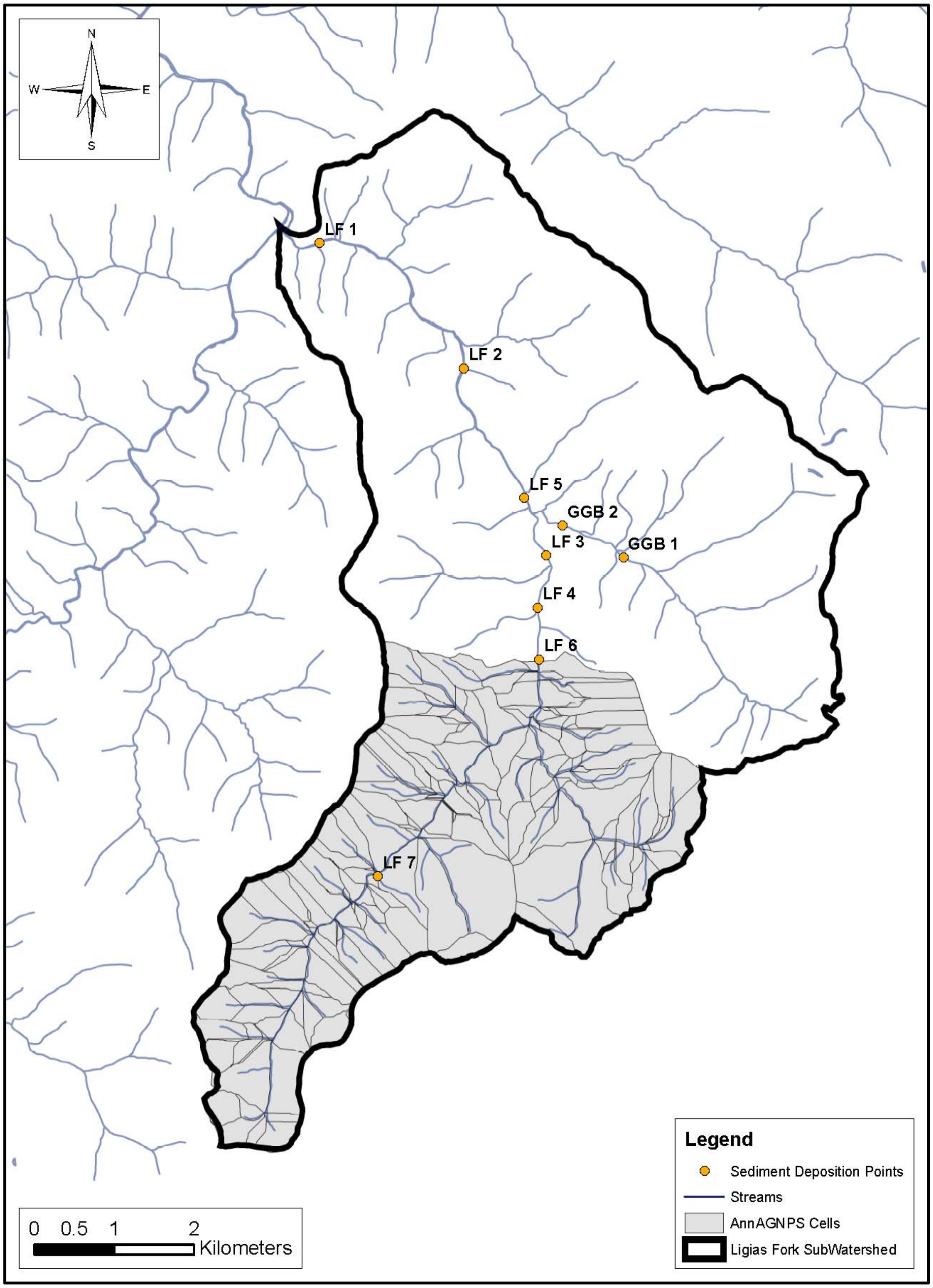
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Ligias Fork SubWatershed
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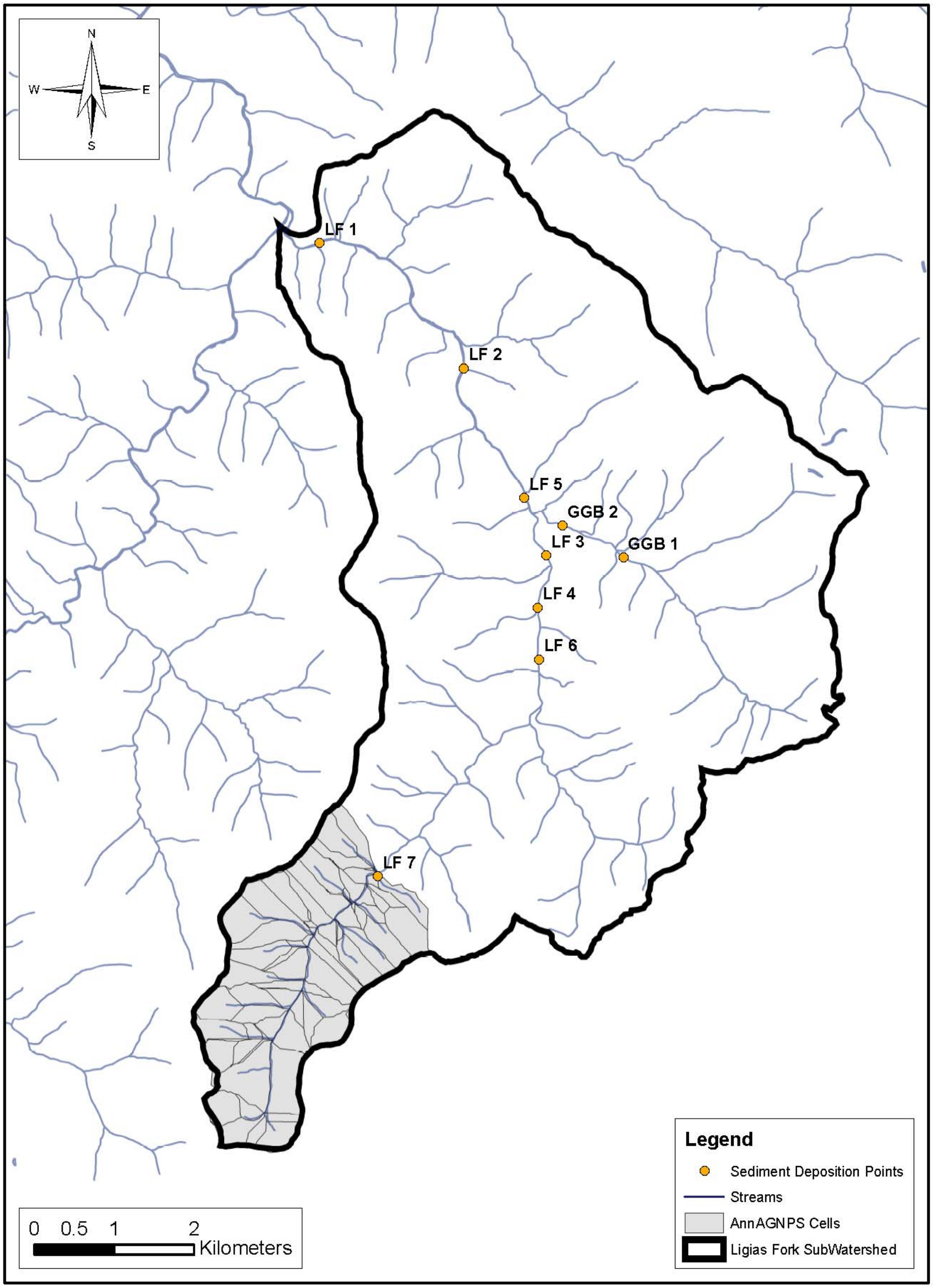
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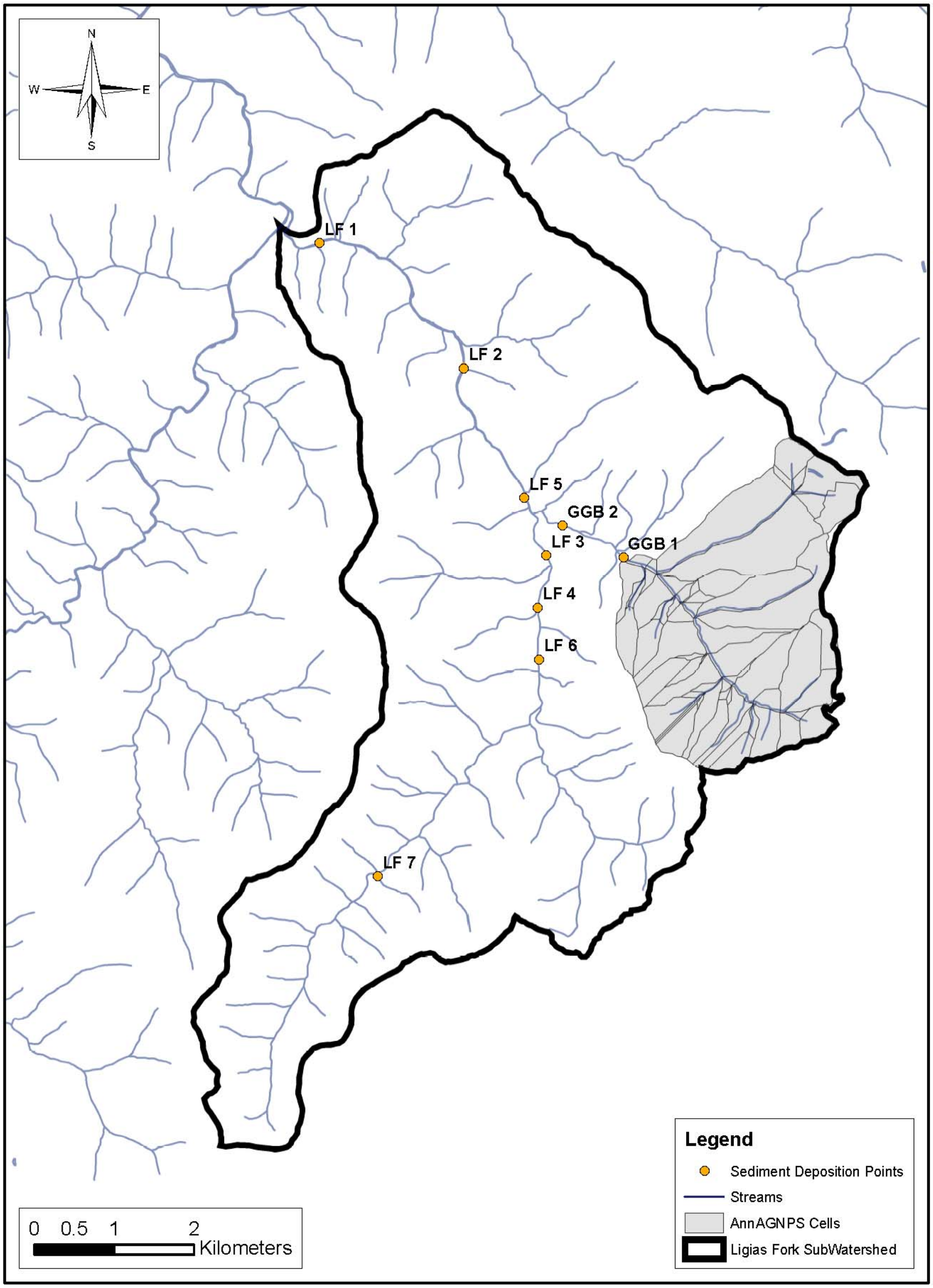
Streams
AnnAGNPS Cells
Ligias Fork SubWatershed
0 0.5 1 2
Kilometers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Streams
AnnAGNPS Cells
Ligias Fork SubWatershed
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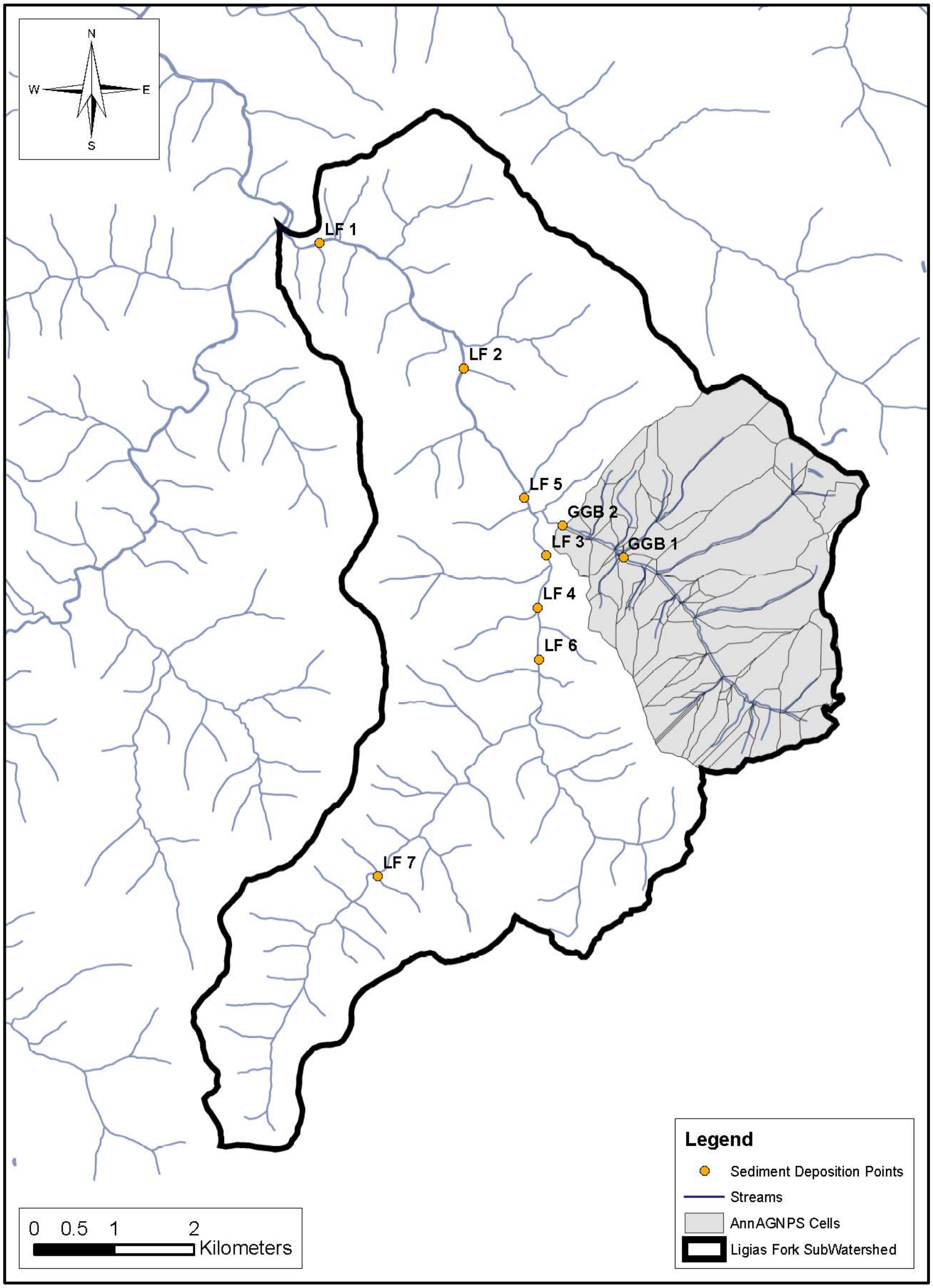
Kilometers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Streams
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Ligias Fork SubWatershed
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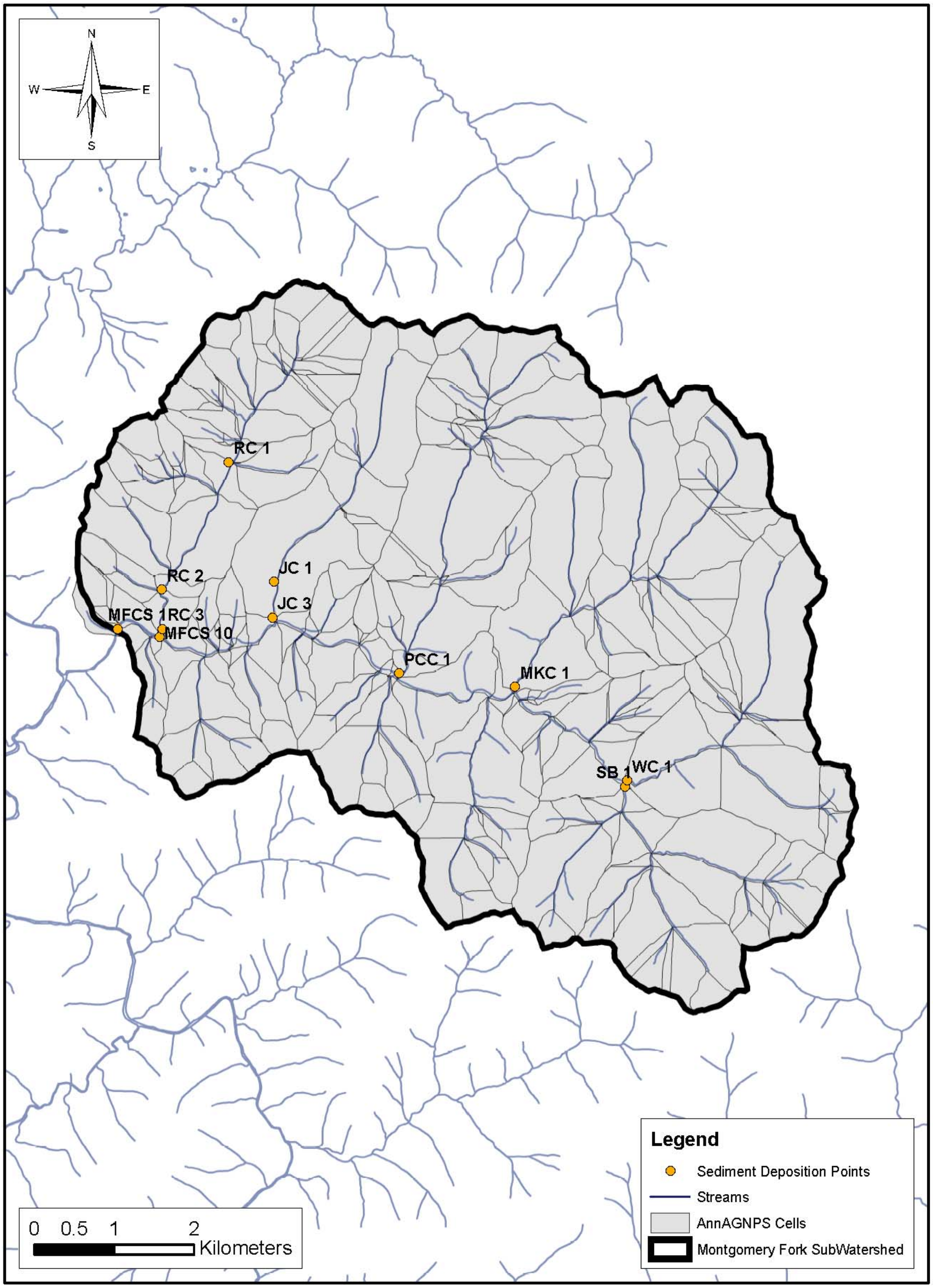
Kilometers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Sediment Deposition Points
Streams
AnnAGNPS Cells
Montgomery Fork SubWatershed
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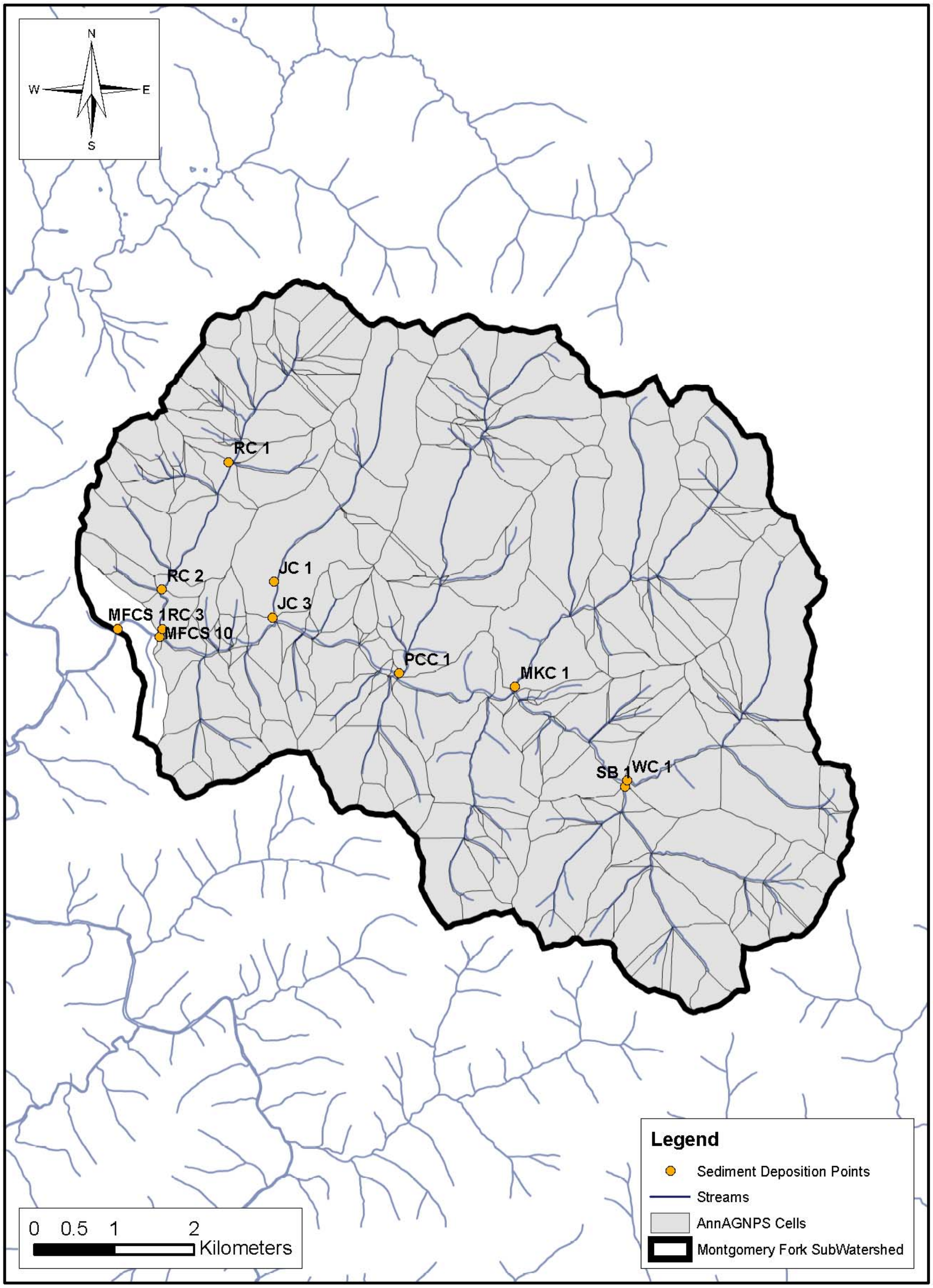
Kilometers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Sediment Deposition Points
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AnnAGNPS Cells
Montgomery Fork SubWatershed
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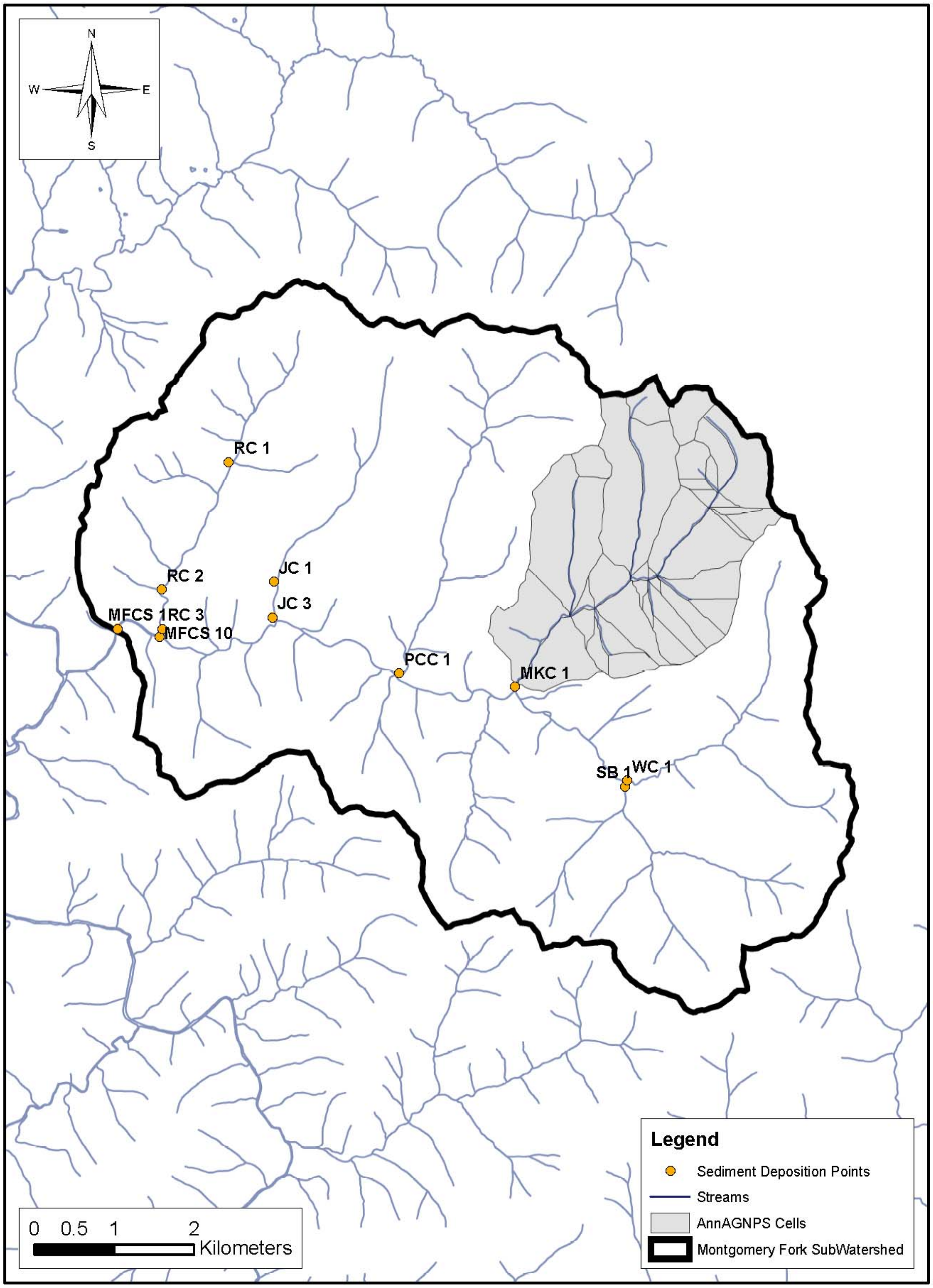

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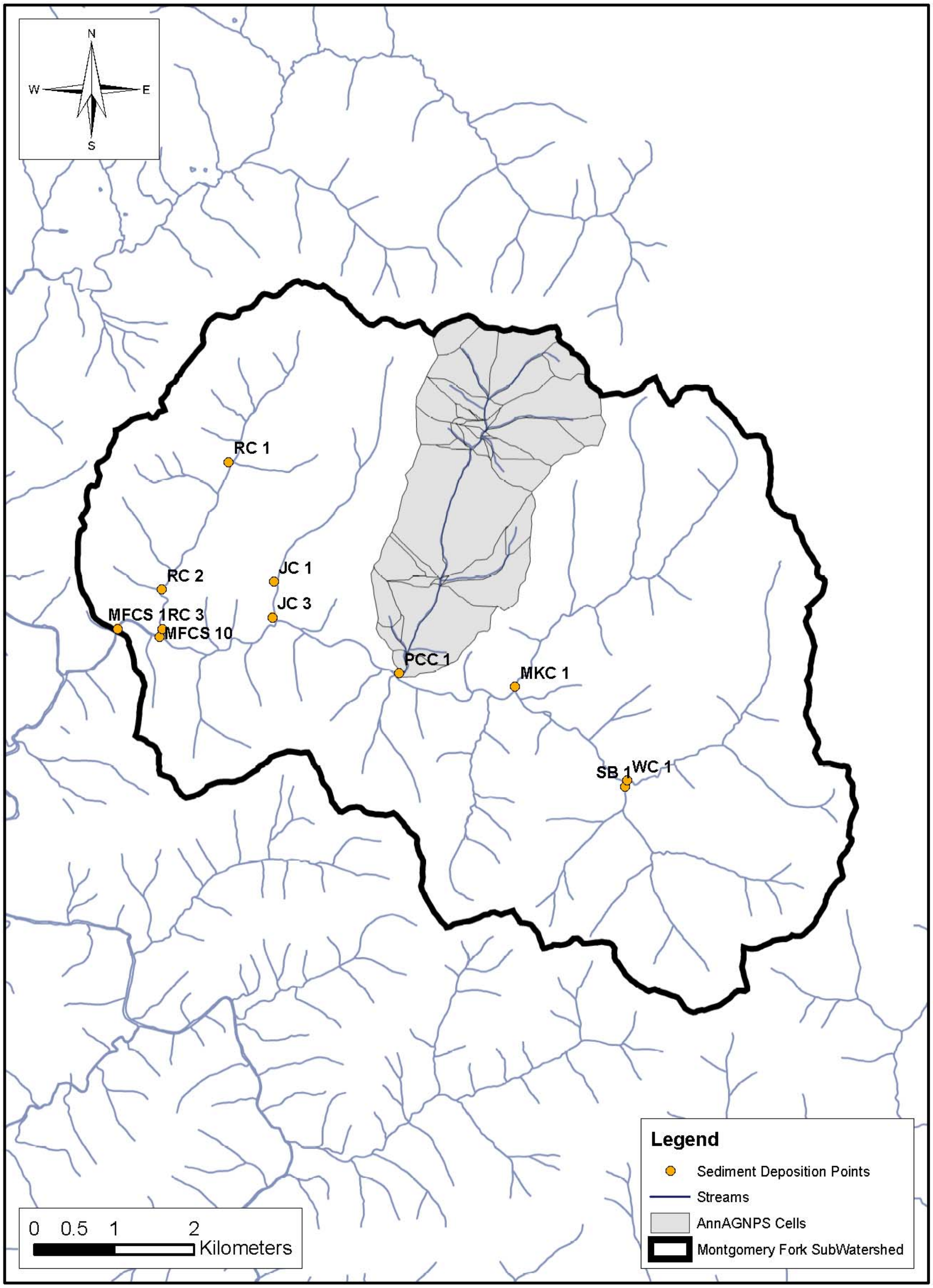
Legend
Sediment Deposition Points
Streams
AnnAGNPS Cells
Montgomery Fork SubWatershed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MFCS 1
RC 3
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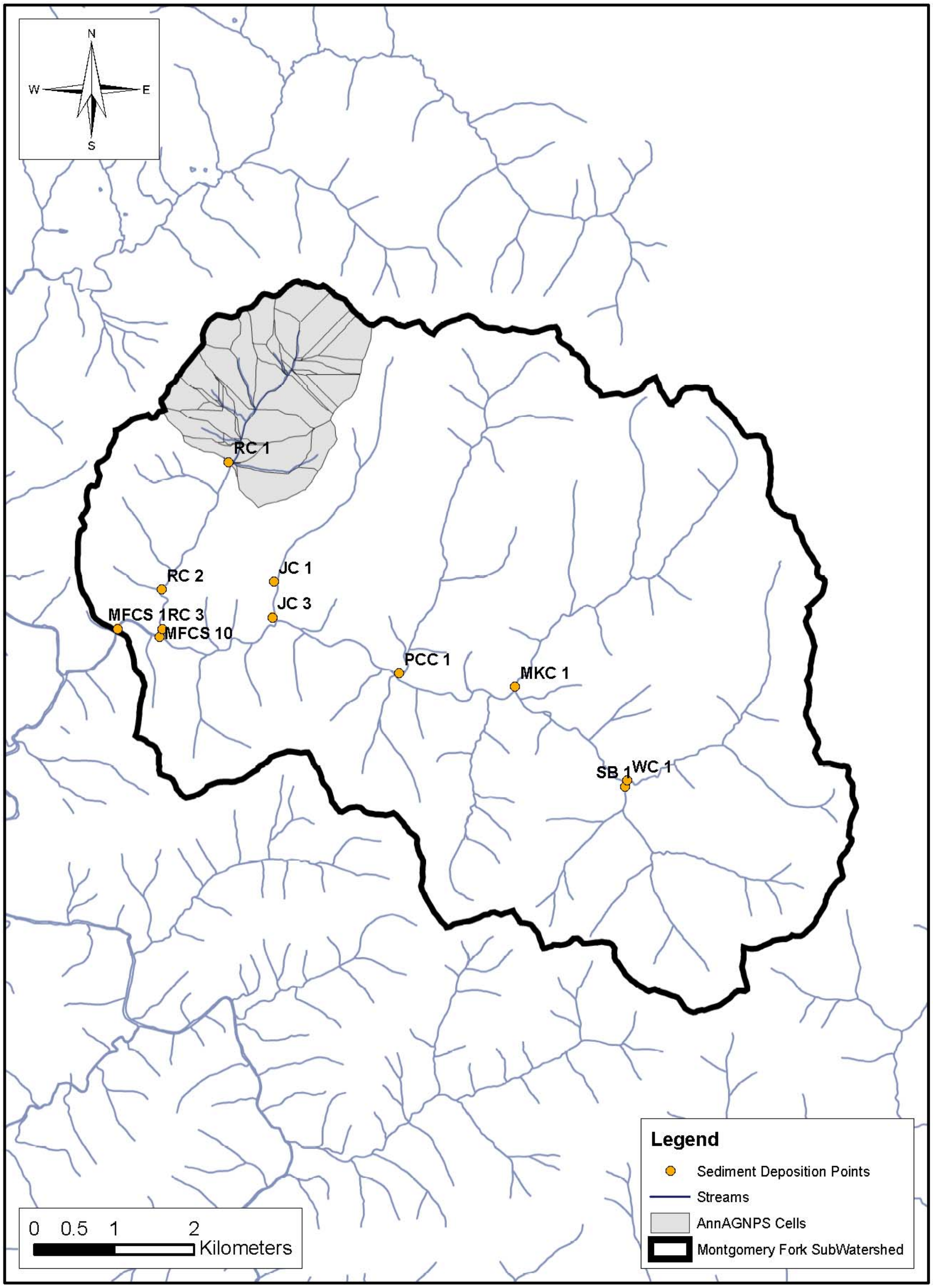
Legend
Sediment Deposition Points
Streams
AnnAGNPS Cells
Montgomery Fork SubWatershed
0 0.5 1 2
Kilometers



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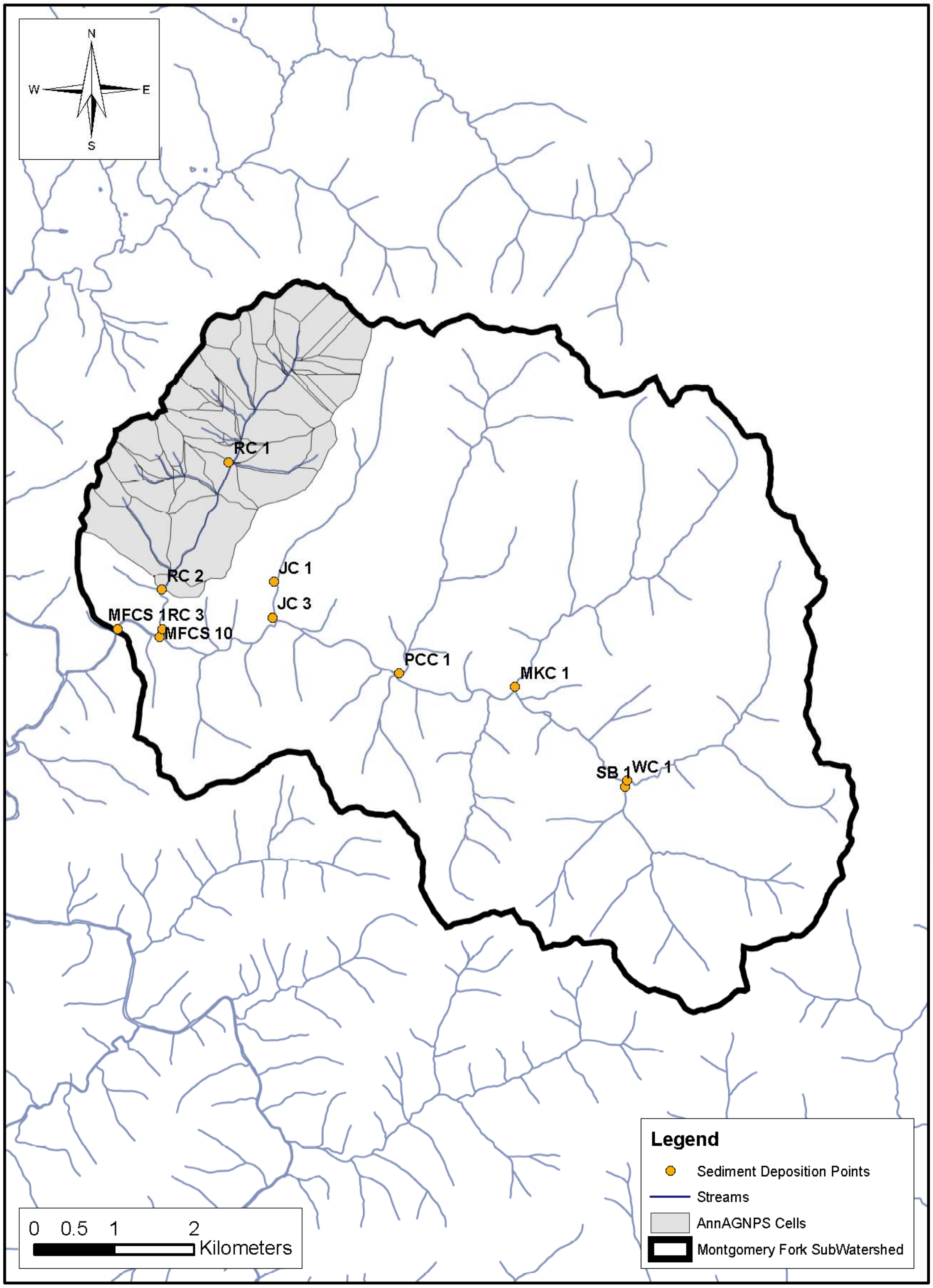
Legend
Sediment Deposition Points
Streams
AnnAGNPS Cells
Montgomery Fork SubWatershed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Legend
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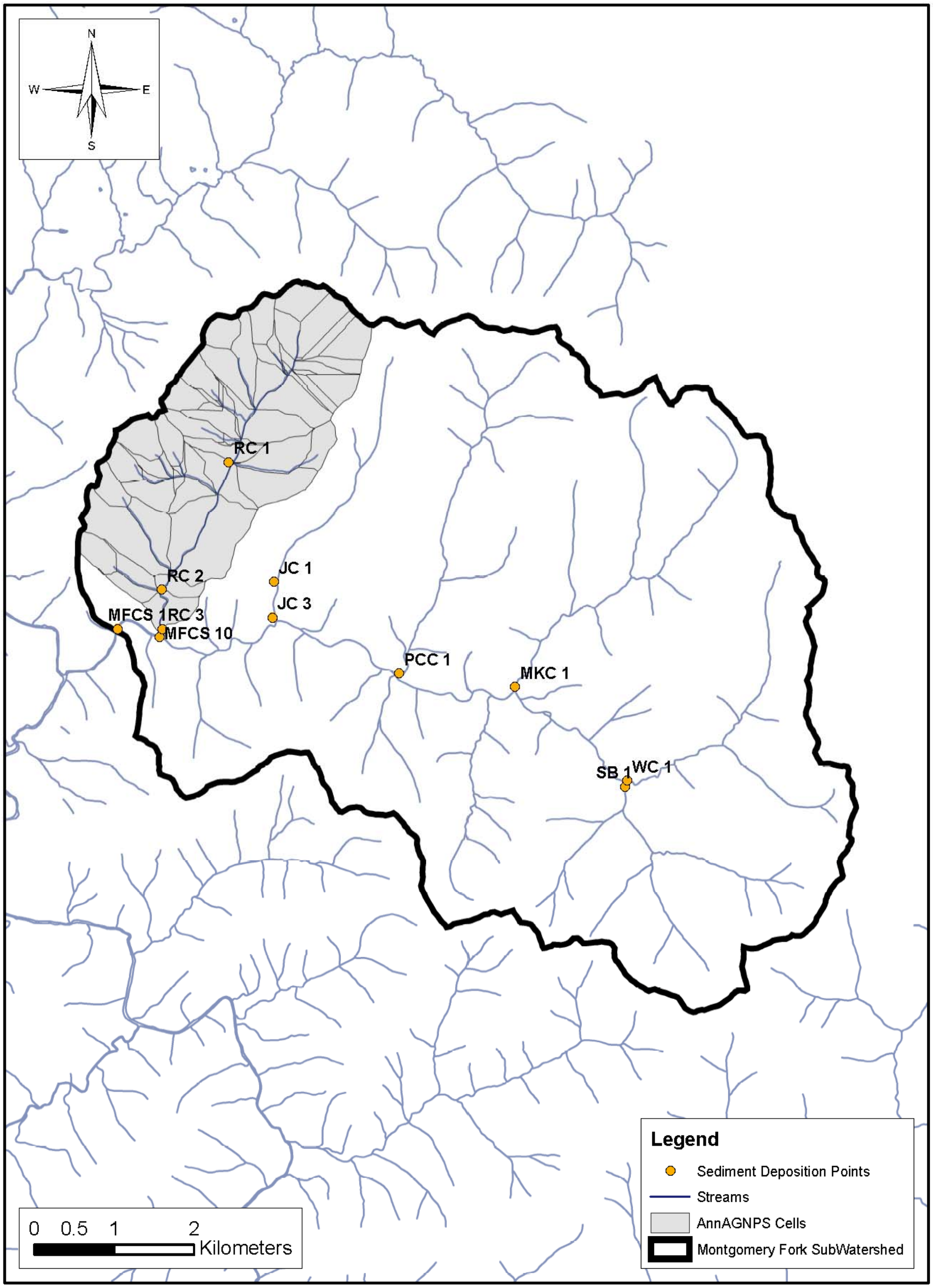
Streams
AnnAGNPS Cells
Montgomery Fork SubWatershed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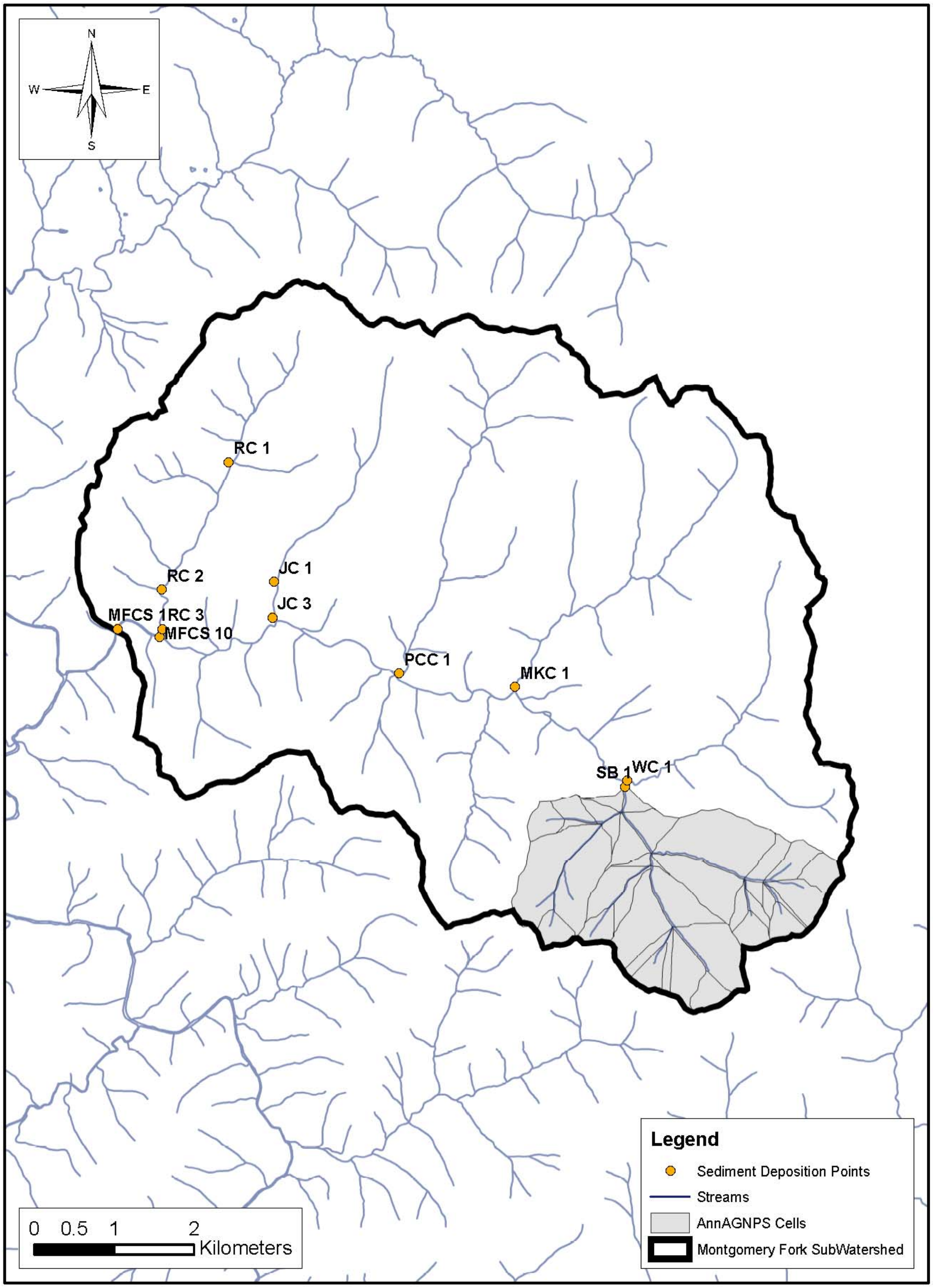
Sediment Deposition Points
Streams
AnnAGNPS Cells
Montgomery Fork SubWatershed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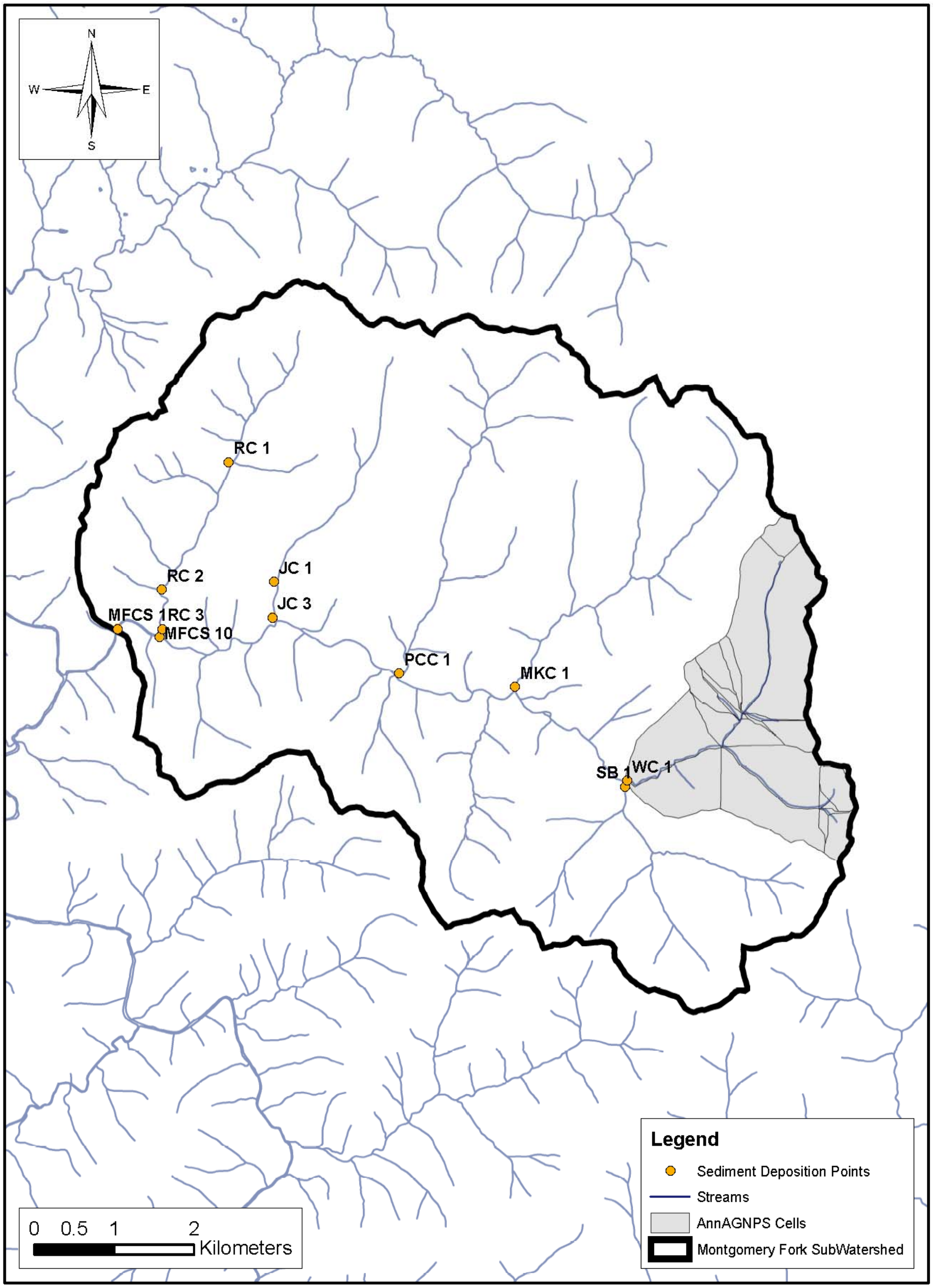
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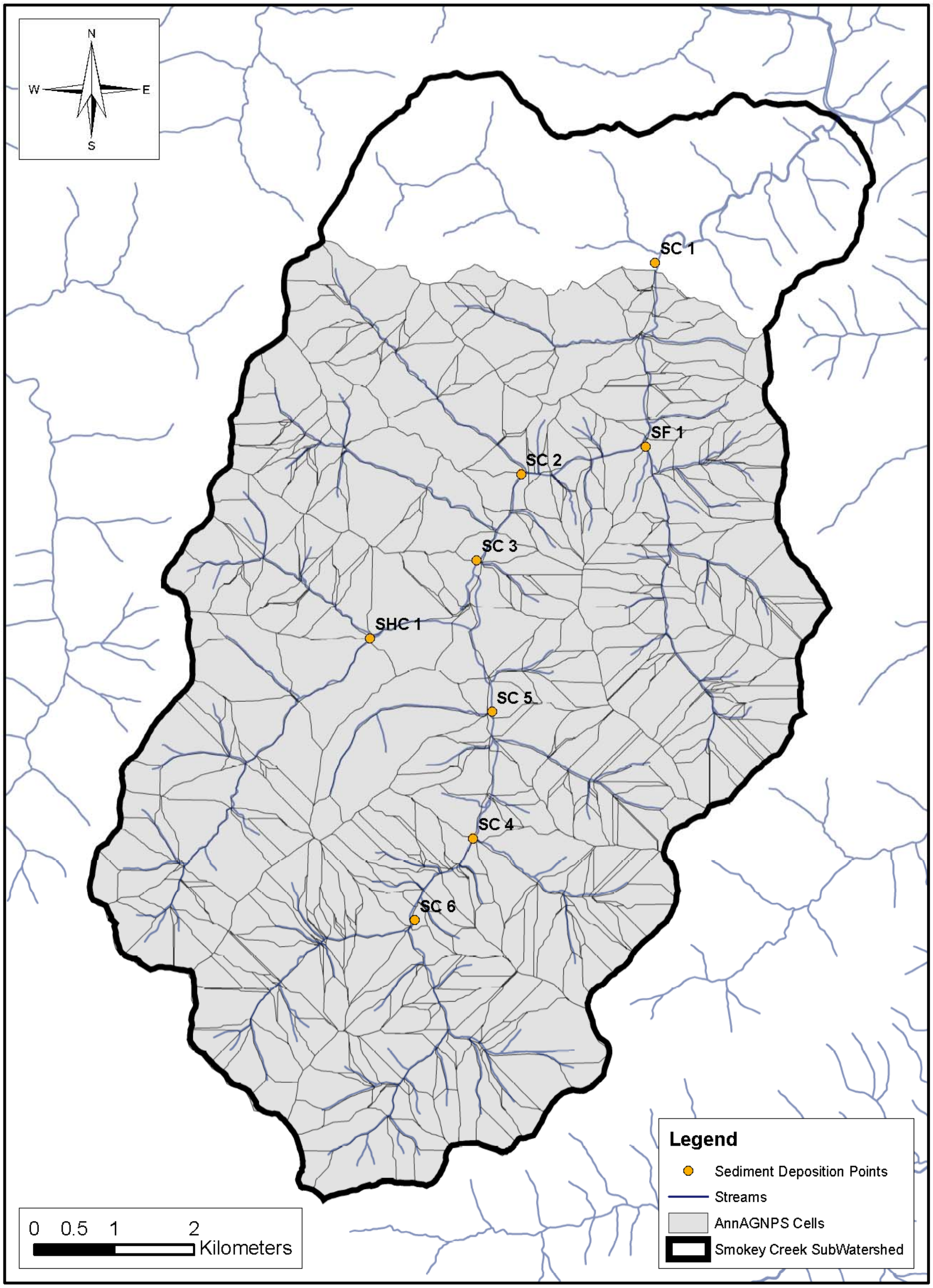
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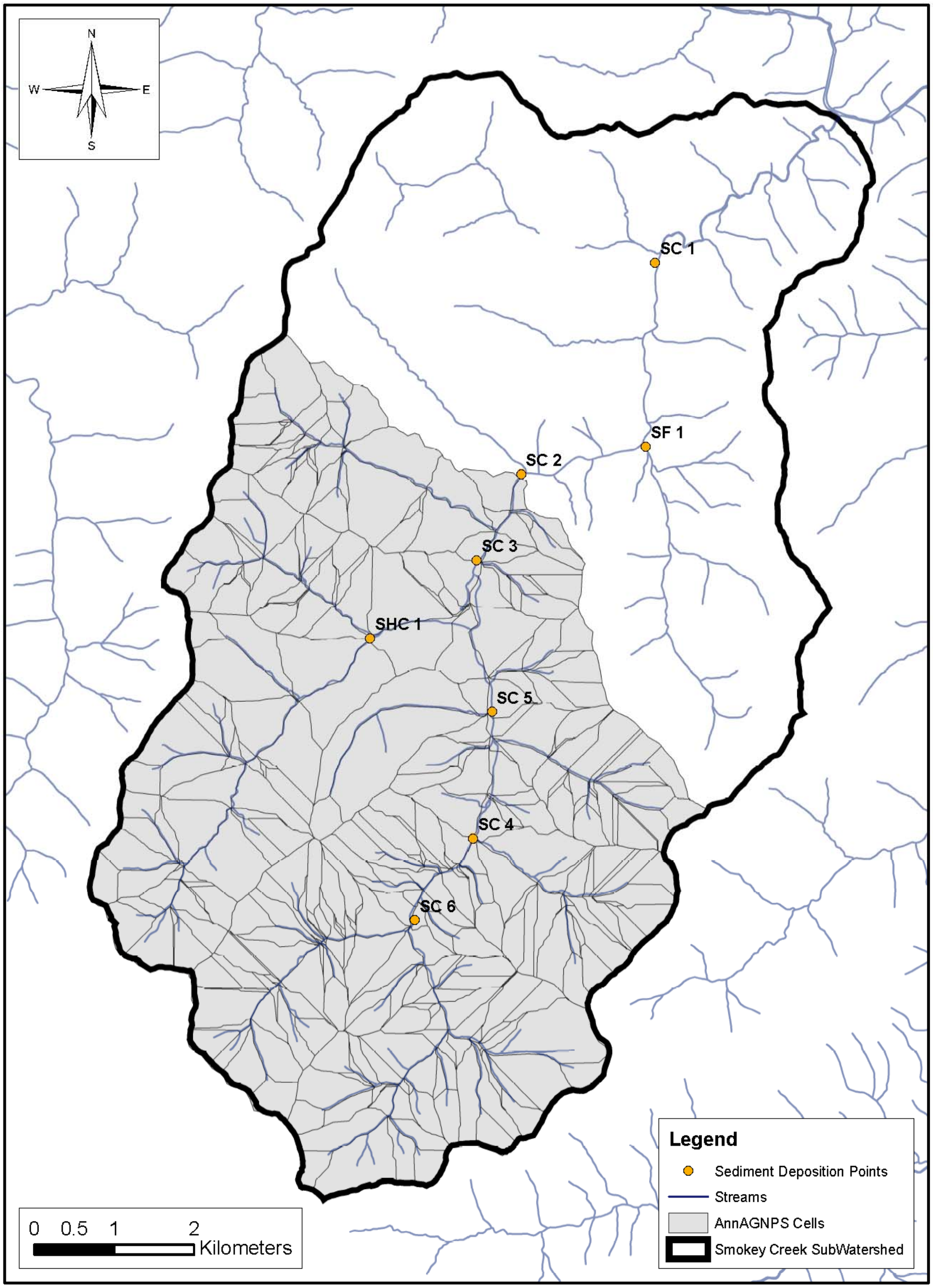
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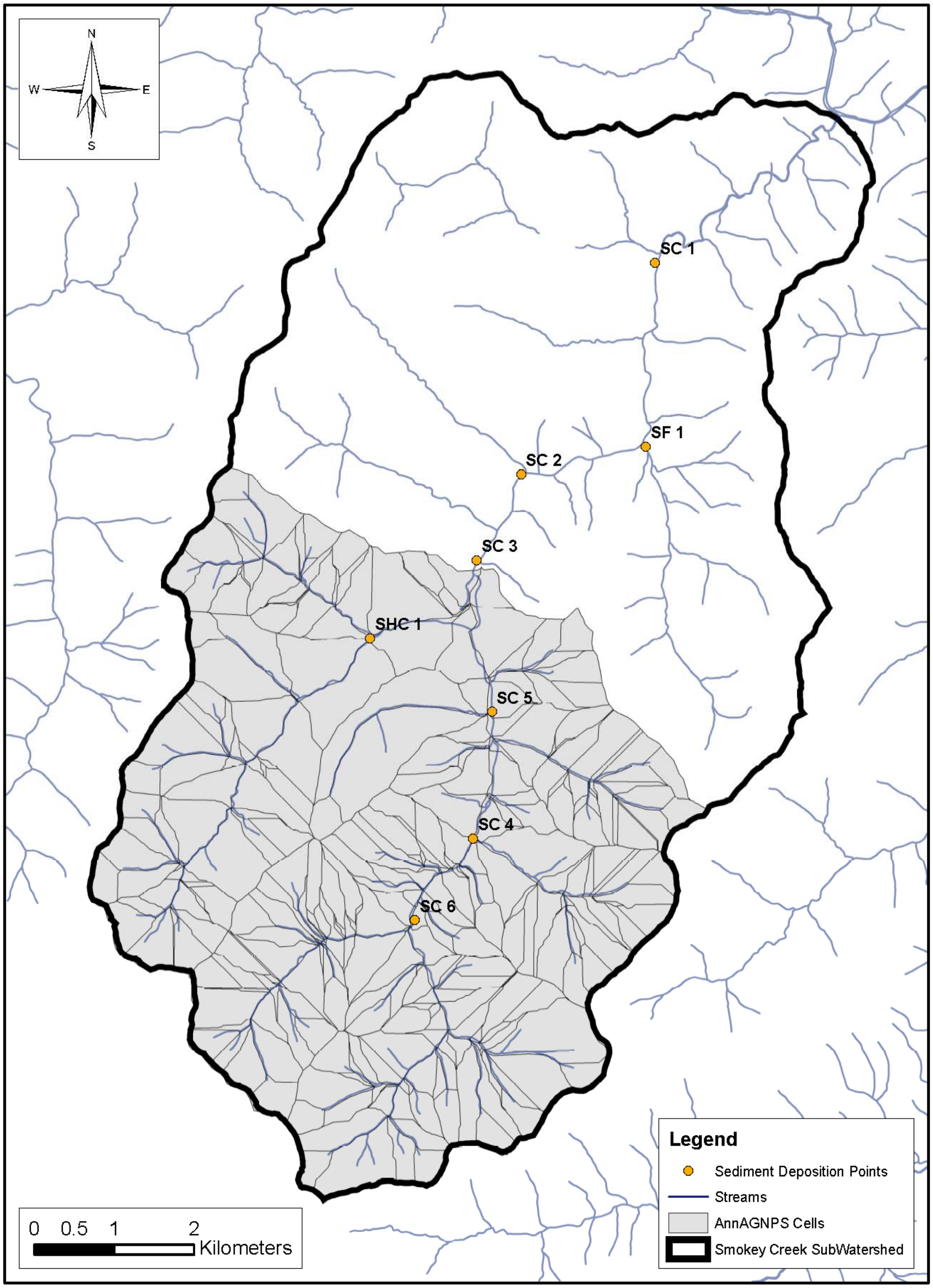
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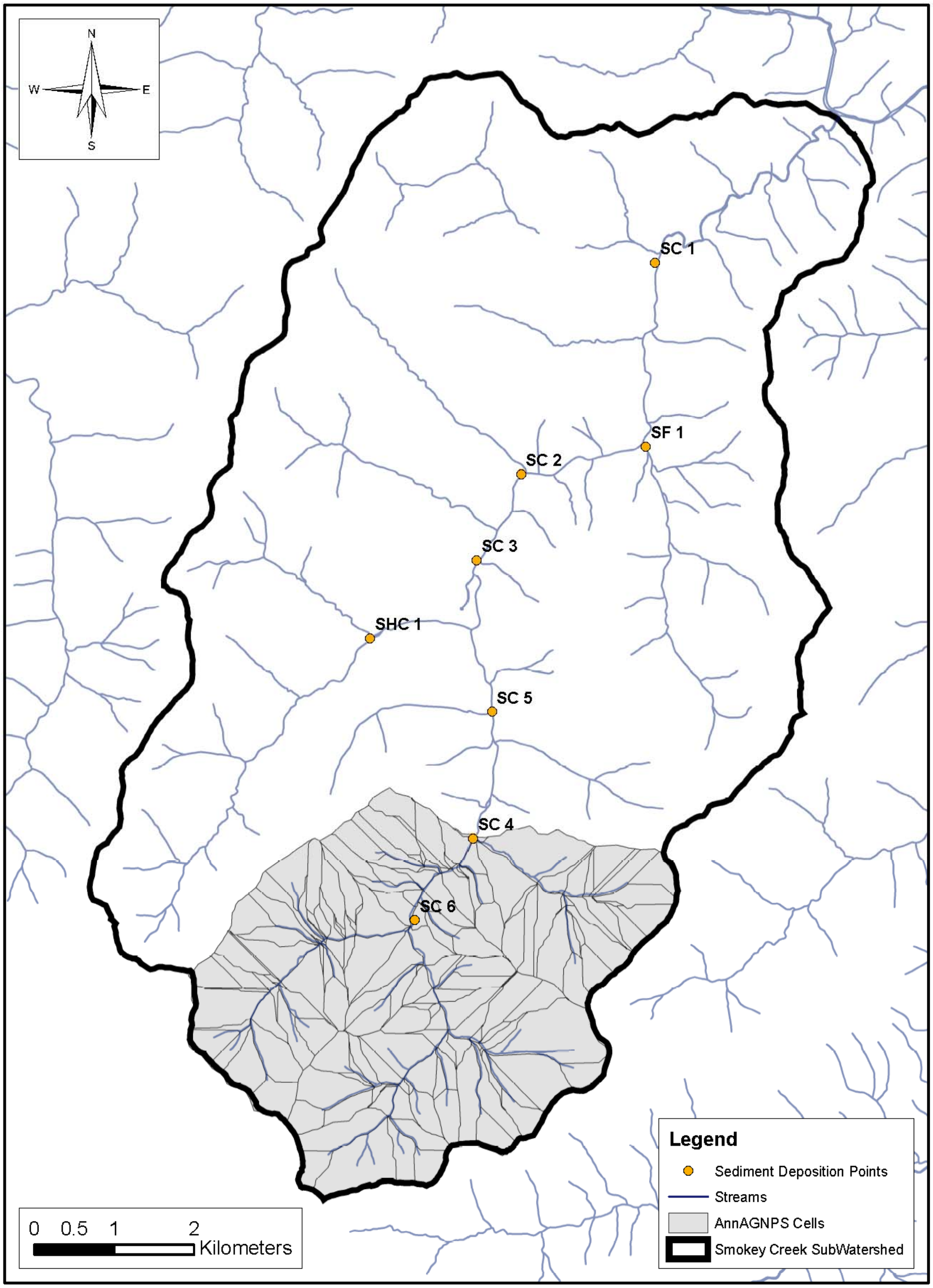
Smokey Creek SubWatershed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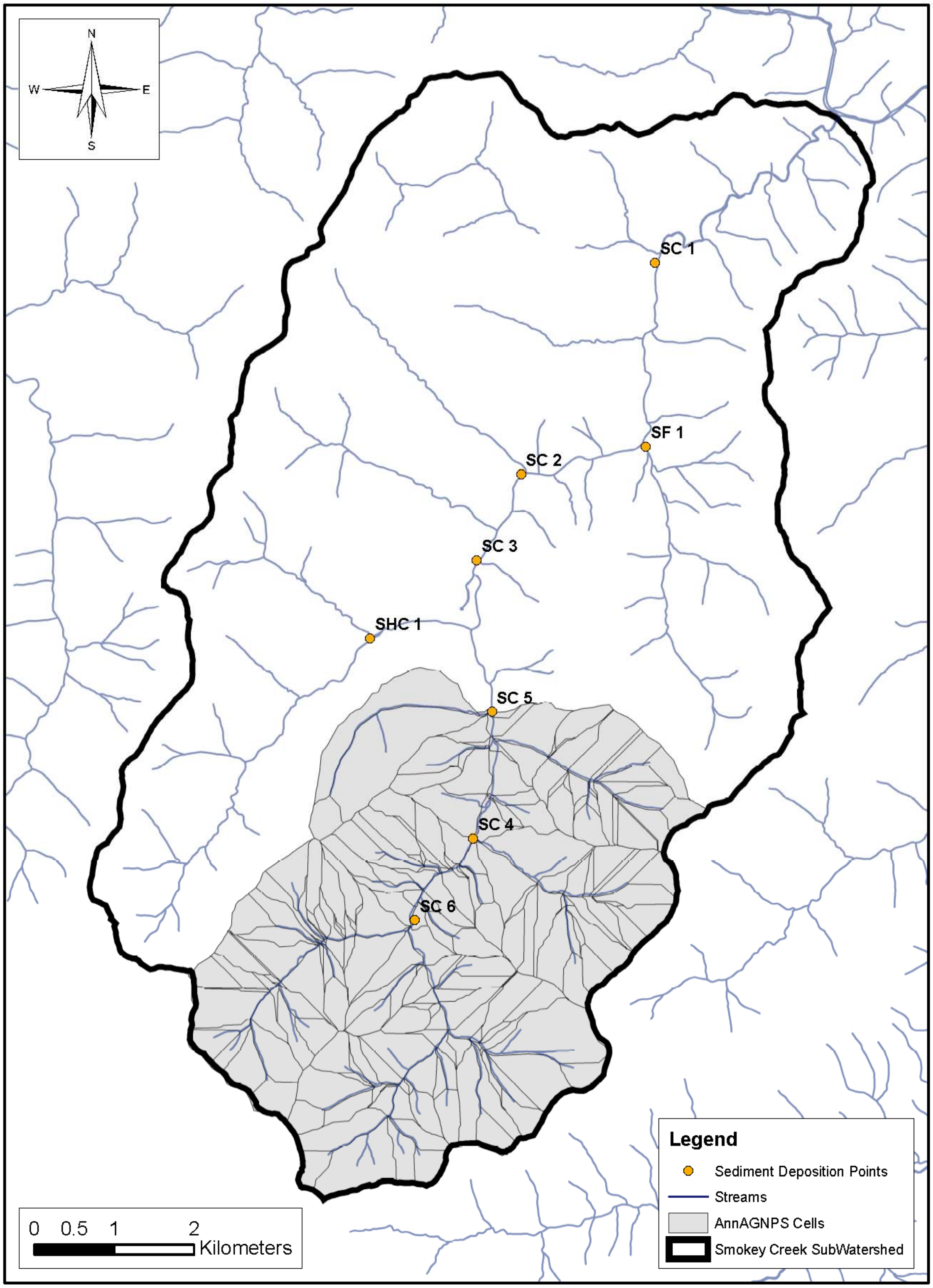
Smokey Creek SubWatershed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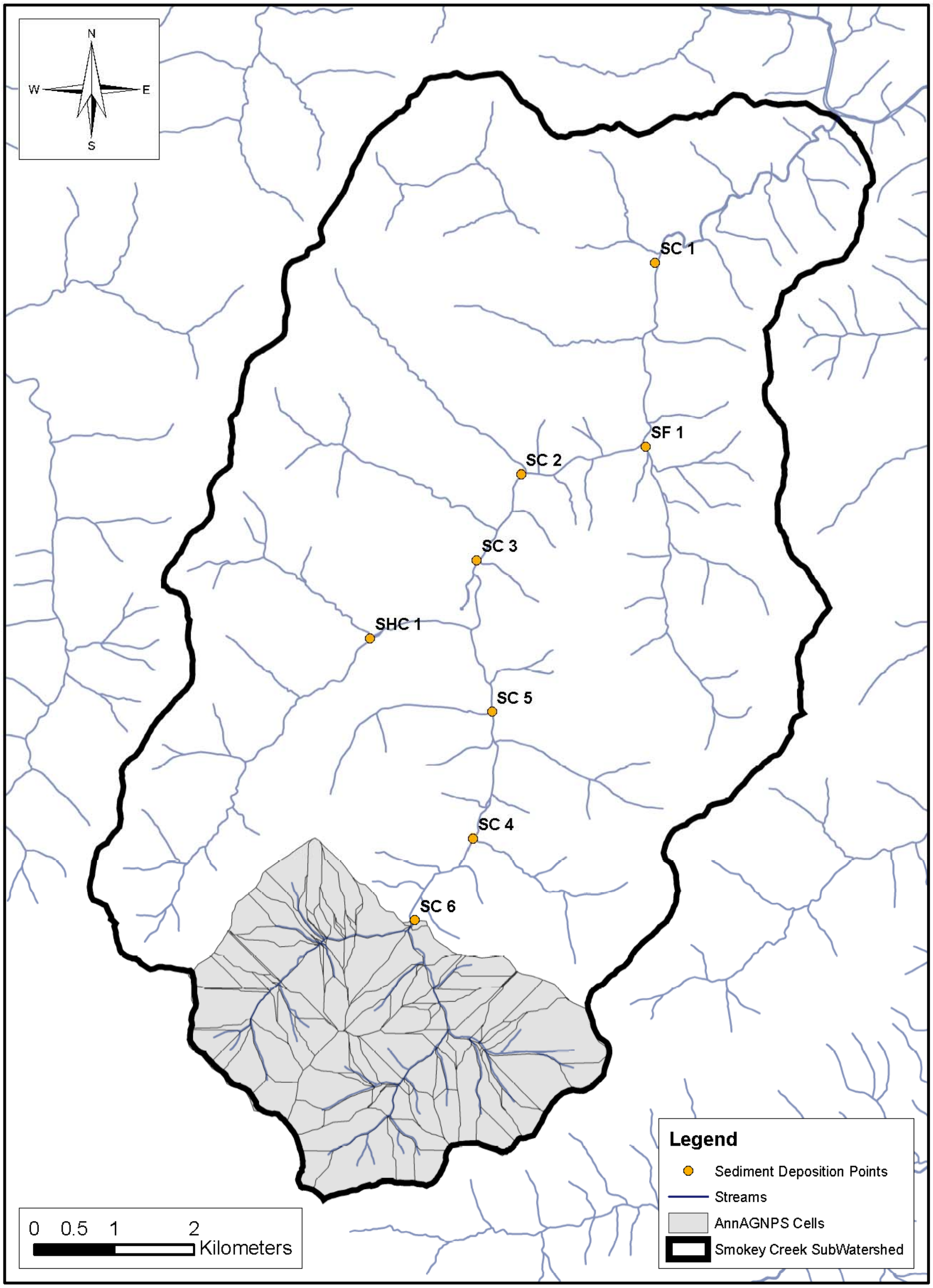
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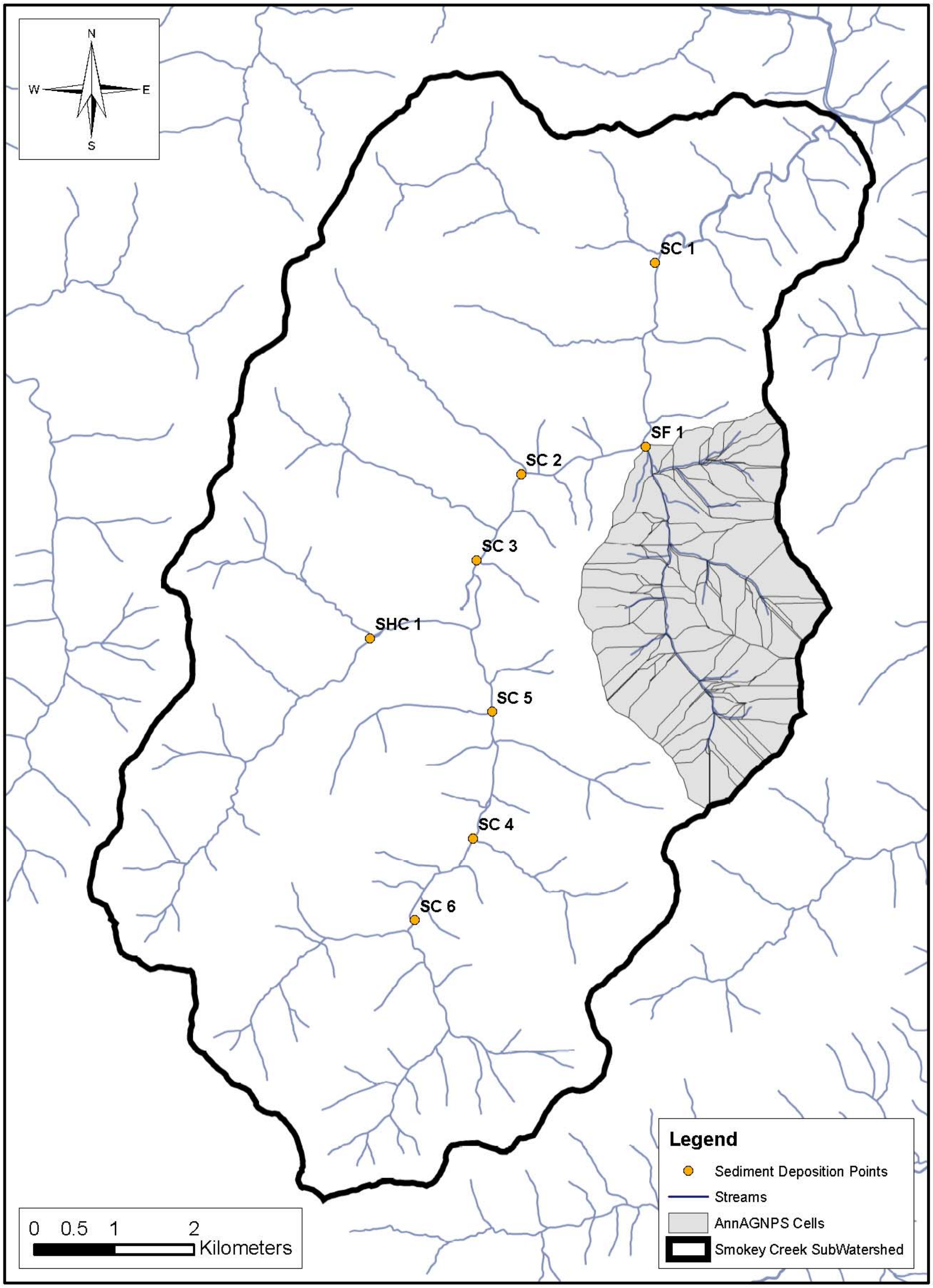
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Smokey Creek SubWatershed
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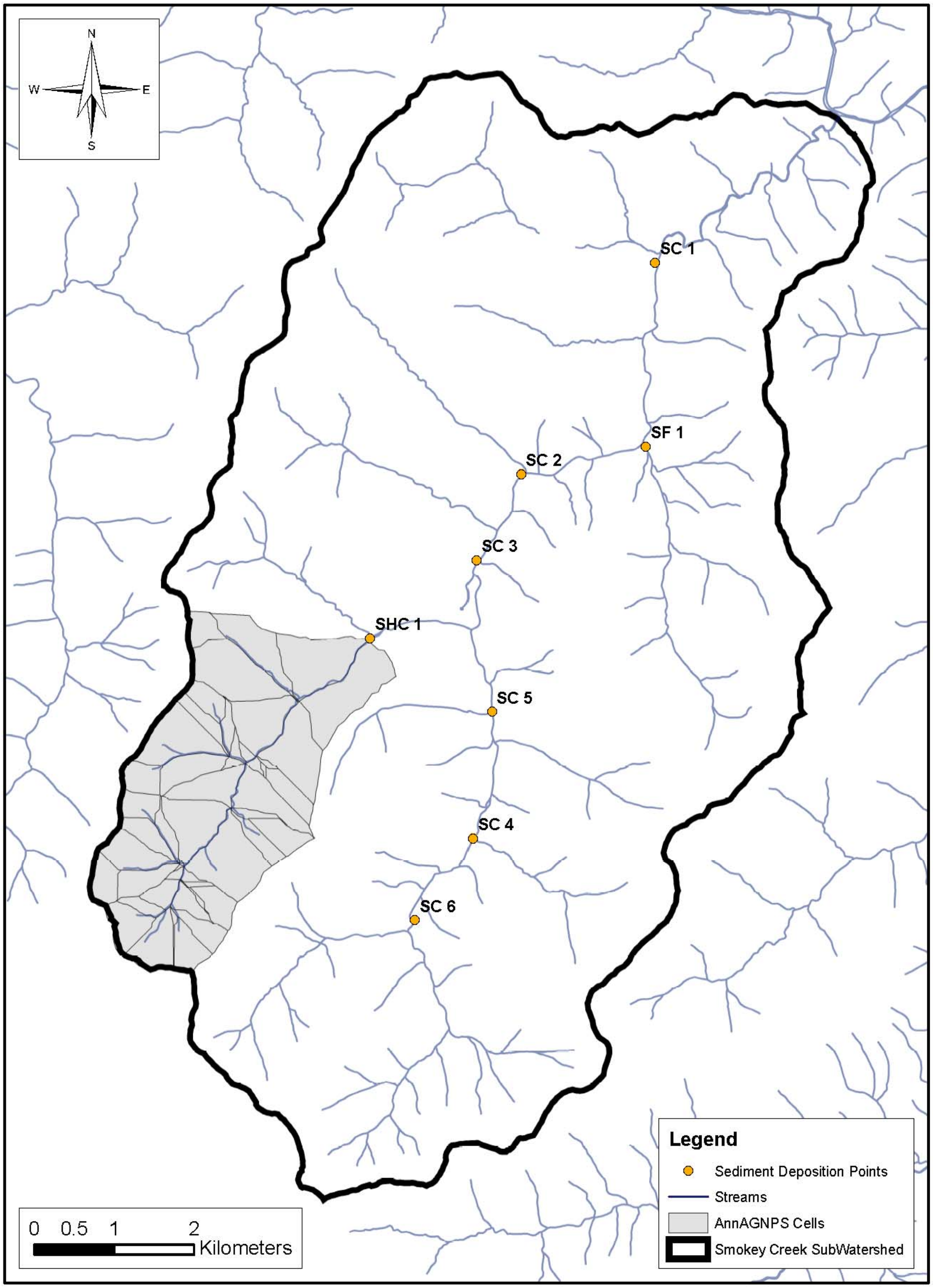
Kilometers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Legend
Sediment Deposition Points
Streams
AnnAGNPS Cells
Smokey Creek SubWatershed
0 0.5 1 2
Kilometers

Appendix G

Statistical Analysis Data

Site ID	Watershed (---)	Drainage Area (ha)	RGA (---)	D_{50} (mm)	D_{84} (mm)	Sediment Particle Size Distribution: Clay Percent (decimal)	Silt Percent (decimal)	Sand Percent (decimal)	Gravel Percent (decimal)	2006 AnnAGNPS Annual Average Sediment Yield: Clay (Mg)	Silt (Mg)	Sand (Mg)	Total (Mg)
BSC-1	Brimstone	2,181	8.5	38.0	98.0	0.00	0.00	0.39	0.61	184	365	23	572
BSC-2	Brimstone	1,813	5.0	34.0	94.0	0.00	0.01	0.48	0.51	182	362	23	567
BSC-3	Brimstone	2,444	7.0	33.0	94.0	0.00	0.01	0.26	0.73	185	368	23	576
JOE-1	Brimstone	1,022	5.0	50.0	124.0	0.00	0.00	0.33	0.66	62	113	0	75
IC-1	Brimstone	538	5.5	42.0	88.0	0.00	0.00	0.27	0.73	9	13	0	22
SC-1	Smokey	7,301	9.0	30.0	58.0	0.00	0.03	0.85	0.12	3,235	6,783	86	10,103
SC-2	Smokey	5,041	9.0	40.0	96.0	0.00	0.00	0.34	0.66	653	1,290	47	1,991
SC-3	Smokey	4,370	8.0	38.0	96.0	0.00	0.00	0.43	0.57	305	578	7	889
SC-4	Smokey	2,001	9.5	46.0	102.0	0.00	0.00	0.55	0.45	141	280	2	423
SC-5	Smokey	2,699	9.0	34.0	74.0	0.00	0.00	0.30	0.70	196	389	3	588
SC-6	Smokey	1,369	10.0	45.0	112.0	0.00	0.01	0.50	0.48	33	64	0	98
SHC-1	Smokey	925	9.0	39.0	94.0	0.00	0.00	0.17	0.83	69	113	48	229
SF-1	Smokey	997	8.5	45.0	104.0	0.00	0.01	0.66	0.33	1,961	4,267	1,080	7,308
MFCS-1	Montgomery	5,748	10.5	30.0	88.0	0.02	0.09	0.55	0.34	1,336	2,815	22	4,172
MFCS-10	Montgomery	5,644	10.0	24.0	49.0	0.00	0.01	0.46	0.53	1,310	2,769	183	4,263
RC-1	Montgomery	454	11.0	16.0	38.0	0.00	0.01	0.36	0.63	351	721	1	1,074
RC-2	Montgomery	770	12.5	14.0	34.0	0.00	0.00	0.12	0.88	670	1,403	67	2,139
RC-3	Montgomery	830	10.5	12.0	32.0	0.00	0.00	0.34	0.66	716	1,496	67	2,278
JC-1	Montgomery	384	7.0	24.0	50.0	0.00	0.00	0.23	0.77	6	13	0	20
JC-3	Montgomery	422	6.0	12.0	24.0	0.00	0.01	0.88	0.12	7	15	0	22
SB-1	Montgomery	724	9.0	25.0	107.0	0.00	0.01	0.20	0.79	22	49	1	73
MKC-1	Montgomery	905	8.0	38.0	114.0	0.00	0.00	0.49	0.51	6	16	0	22
PCC-1	Montgomery	748	10.0	34.0	87.0	0.00	0.01	0.48	0.50	4	14	0	18
WC-1	Montgomery	611	7.0	41.0	104.0	0.00	0.00	0.26	0.24	9	21	0	30
LF-1	Ligias	5,218	8.5	46.0	88.0	0.00	0.01	0.44	0.55	610	1,010	7	1,628
LF-2	Ligias	4,237	9.0	44.0	87.0	0.00	0.00	0.87	0.13	380	558	5	943
LF-3	Ligias	2,338	7.5	34.0	178.0	0.00	0.00	0.40	0.60	121	272	29	422
LF-4	Ligias	2,058	9.0	45.0	110.0	0.00	0.00	0.24	0.76	118	267	29	414
LF-5	Ligias	3,699	12.0	49.0	104.0	0.00	0.00	0.41	0.58	377	557	96	1,030
LF-6	Ligias	1,929	7.0	60.0	170.0	0.00	0.00	0.26	0.74	117	265	29	411
LF-7	Ligias	663	9.0	60.0	170.0	0.00	0.00	0.24	0.76	27	34	2	63
GGB-1	Ligias	836	6.0	56.0	232.0	0.00	0.00	0.56	0.44	211	238	58	506
GGB-2	Ligias	1,229	8.5	38.0	118.0	0.00	0.02	0.29	0.70	263	294	69	626

Site ID	Watershed (---)	Drainage Area (ha)	RGA (---)	D_{50} (mm)	D_{84} (mm)	Sediment Particle Size Distribution: Clay Percent (decimal)	Silt Percent (decimal)	Sand Percent (decimal)	Gravel Percent (decimal)	2007 AnnAGNPS Annual Average Sediment Yield: Clay (Mg)	Silt (Mg)	Sand (Mg)	Total (Mg)
BSC-1	Brimstone	2,181	8.5	38.0	98.0	0.00	0.00	0.39	0.61	80	159	9	248
BSC-2	Brimstone	1,813	5.0	34.0	94.0	0.00	0.01	0.48	0.51	79	158	10	246
BSC-3	Brimstone	2,444	7.0	33.0	94.0	0.00	0.01	0.26	0.73	81	160	9	250
JOE-1	Brimstone	1,022	5.0	50.0	124.0	0.00	0.00	0.33	0.66	27	49	0	76
IC-1	Brimstone	538	5.5	42.0	88.0	0.00	0.00	0.27	0.73	3	4	0	22
SC-1	Smokey	7,301	9.0	30.0	58.0	0.00	0.03	0.85	0.12	1,494	3,113	35	4,642
SC-2	Smokey	5,041	9.0	40.0	96.0	0.00	0.00	0.34	0.66	275	544	18	837
SC-3	Smokey	4,370	8.0	38.0	96.0	0.00	0.00	0.43	0.57	125	237	1	363
SC-4	Smokey	2,001	9.5	46.0	102.0	0.00	0.00	0.55	0.45	58	116	0	175
SC-5	Smokey	2,699	9.0	34.0	74.0	0.00	0.00	0.30	0.70	82	163	1	246
SC-6	Smokey	1,369	10.0	45.0	112.0	0.00	0.01	0.50	0.48	13	26	0	39
SHC-1	Smokey	925	9.0	39.0	94.0	0.00	0.00	0.17	0.83	27	44	21	92
SF-1	Smokey	997	8.5	45.0	104.0	0.00	0.01	0.66	0.33	864	1,877	469	3,210
MFCS-1	Montgomery	5,748	10.5	30.0	88.0	0.02	0.09	0.55	0.34	625	1,312	5	1,942
MFCS-10	Montgomery	5,644	10.0	24.0	49.0	0.00	0.01	0.46	0.53	613	1,291	80	1,984
RC-1	Montgomery	454	11.0	16.0	38.0	0.00	0.01	0.36	0.63	143	294	0	437
RC-2	Montgomery	770	12.5	14.0	34.0	0.00	0.00	0.12	0.88	284	594	27	905
RC-3	Montgomery	830	10.5	12.0	32.0	0.00	0.00	0.34	0.66	304	634	27	964
JC-1	Montgomery	384	7.0	24.0	50.0	0.00	0.00	0.23	0.77	2	5	0	7
JC-3	Montgomery	422	6.0	12.0	24.0	0.00	0.01	0.88	0.12	2	5	0	7
SB-1	Montgomery	724	9.0	25.0	107.0	0.00	0.01	0.20	0.79	8	18	0	26
MKC-1	Montgomery	905	8.0	38.0	114.0	0.00	0.00	0.49	0.51	3	8	0	11
PCC-1	Montgomery	748	10.0	34.0	87.0	0.00	0.01	0.48	0.50	2	7	0	9
WC-1	Montgomery	611	7.0	41.0	104.0	0.00	0.00	0.26	0.24	3	8	0	12
LF-1	Ligias	5,218	8.5	46.0	88.0	0.00	0.01	0.44	0.55	328	547	2	877
LF-2	Ligias	4,237	9.0	44.0	87.0	0.00	0.00	0.87	0.13	204	301	1	507
LF-3	Ligias	2,338	7.5	34.0	178.0	0.00	0.00	0.40	0.60	64	149	15	228
LF-4	Ligias	2,058	9.0	45.0	110.0	0.00	0.00	0.24	0.76	62	146	15	224
LF-5	Ligias	3,699	12.0	49.0	104.0	0.00	0.00	0.41	0.58	202	301	51	555
LF-6	Ligias	1,929	7.0	60.0	170.0	0.00	0.00	0.26	0.74	62	145	15	223
LF-7	Ligias	663	9.0	60.0	170.0	0.00	0.00	0.24	0.76	11	15	1	27
GGB-1	Ligias	836	6.0	56.0	232.0	0.00	0.00	0.56	0.44	107	119	29	256
GGB-2	Ligias	1,229	8.5	38.0	118.0	0.00	0.02	0.29	0.70	136	151	36	323

Vita

Michael Patrick Massey was born and raised in the modest town of Lawrenceburg, Tennessee. He attended Lawrence County High School and graduated with an honors diploma in 2001. After graduating from high school, Patrick completed a year at Tennessee Technological University in Cookeville, TN and then transferred to The University of Tennessee, Knoxville to complete his Bachelor's Degree in Civil Engineering. After spending numerous semesters of engineering study in Knoxville, Patrick took an internship position during the middle of his junior year with Jackson Energy Authority in Jackson, TN. After a one-year internship was completed with the West Tennessee utility company, Patrick began working part-time with Knoxville Utilities Board as he finished up his last year of engineering studies. In the fall of 2006, Patrick obtained a B.S. in Civil Engineering with a 4.0 GPA. He was announced as the Top Graduate in the College of Engineering at The University of Tennessee, Knoxville. Immediately after receiving his bachelor's degree, Patrick was offered a graduate research assistant position at The University of Tennessee, Knoxville with the Water Resources Environmental Engineering Department. After many laborious hours conducting research for two contractual agreements from the U.S. Department of Interior – Office of Surface Mining division and taking several graduate level environmental engineering courses, Patrick earned a Master's of Science in Environmental Engineering in the spring of 2008.